

Summary of the FAA's Review of the Boeing 737 MAX



**Federal Aviation
Administration**

Summary of the FAA's Review of the Boeing 737 MAX

Return to Service of the Boeing 737 MAX Aircraft

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Executive Summary

Introduction

This report provides a detailed technical account of the lessons learned since the two fatal accidents involving the Boeing 737 MAX aircraft, as well as actions the U.S. Federal Aviation Administration (FAA) took to ensure the airplane's safe return to service. As the State of Design agent, the FAA is providing this report to all States of Registry and to the general public to explain how the agency identified and addressed the safety issues affecting the 737 MAX.

The FAA's intent is to assure the global community that the 737 MAX is safe to operate and meets FAA certification standards. This report contains details of the FAA's comprehensive review of the manufacturer's proposed changes to the airplane's Maneuvering Characteristics Augmentation System (MCAS). This includes associated system parts, software and mechanical characteristics, safety assumptions, and systems assessments. Additionally, this report discusses the design, operation, revised pilot training, and maintenance changes that effectively address the causes of the Lion Air Flight 610 (JT610) and Ethiopian Airlines Flight 302 (ET302) accidents.

During its evaluation of Boeing's proposed modifications, the FAA retained all compliance findings and approvals associated with the design changes related to MCAS. This thorough review has taken more than 22 months and included the full-time work of more than 40 engineers, inspectors, pilots, and technical support staff. The effort represents more than 60,000 FAA hours of review, certification testing, and evaluation of pertinent documents. This includes approximately 50 hours of FAA flight or simulator tests and FAA analysis of more than 4,000 hours of company flight and simulator testing.

The FAA has a longstanding commitment to transparency, continuous improvement, and information sharing to encourage increased aviation safety worldwide. To these ends, the agency supported numerous reviews, investigations, and robust international engagement with fellow Civil Aviation Authorities (CAAs). The FAA took into account the final recommendations of the U.S. National Transportation Safety Board (NTSB) and Indonesia's Komite Nasional Keselamatan Transportasi (KNKT), as well as all available preliminary information from the accident investigations.

The FAA and other U.S. bodies commissioned a number of studies to evaluate the initial certification of the 737 MAX, as well as the certification process itself. The FAA invited nine other CAAs to be a part of the Joint Authorities Technical Review (JATR), which assessed the certification of the 737 MAX flight control system. The FAA took into consideration all relevant findings of the JATR, as well as those of the U.S. Department of Transportation Special Committee, the U.S. Department of Transportation Office of the Inspector General (OIG), and other expert reviews.

The FAA also commissioned a Technical Advisory Board (TAB) to independently review Boeing's proposed corrective actions. The TAB consisted of a number of technical experts

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with no involvement in the initial certification of the 737 MAX. Several of these experts were from other U.S. government agencies. The actions by the FAA and Boeing, summarized in this report, adopted the TAB's recommendations.

This summary is part of FAA's extensive outreach to technical experts from CAAs around the globe to address their concerns about the aircraft. The FAA also actively supported concurrent validation activities of the aircraft by the CAAs of other States of Design of large transport airplanes. Each authority will make its own assessment of the FAA's process and findings, as well as Boeing's actions to address the findings.

Due to the nature of the certification process, the FAA continually engaged with the CAAs on all aspects of the review. Likewise, all of the CAAs reviewed identical data from Boeing to make their respective findings.

Details of the aircraft's flight control system, as well as the FAA's evaluation and validation of the changes to the design of the flight control system, are contained in the body of this report. This report also includes the FAA's decision-making logic and supporting information.

Post-Accident Actions

On October 29, 2018, Lion Air Flight 610 (JT610), a Boeing 737 MAX, crashed shortly after takeoff in Jakarta, Indonesia. On November 5, 2018, after evidence emerged of a potential contributor to the accident, the FAA conducted a preliminary risk assessment using the continued operation safety process established in FAA Order 8110.107A, *Monitor Safety/Analyze Data (MSAD)*. Based on this risk assessment, the FAA determined urgent mandatory action was needed.

On November 6, 2018, the FAA issued a Continued Airworthiness Notification to the International Community (CANIC) (see Appendix D) to notify CAAs around the world that the FAA intended to issue an Emergency Airworthiness Directive (AD) to correct an unsafe condition on all 737 MAX aircraft. On November 7, 2018, the FAA issued Emergency AD 2018-23-51 (see Appendix C) requiring flight crews to use a revised runaway stabilizer operational procedure if they encountered certain conditions. The Emergency AD was an interim action, and further action was planned based on what the FAA and Boeing learned from investigating the JT610 accident.

On March 10, 2019, Ethiopian Airlines Flight 302, also a Boeing 737 MAX airplane, crashed shortly after takeoff in Addis Ababa, Ethiopia. Partial data (e.g., altitude, airspeed and vertical speed) was available from a land-based Automatic Dependent Surveillance—Broadcast (ADS-B) system. On March 11, 2019, the FAA issued another CANIC (see Appendix D) indicating the FAA was actively involved in supporting the investigations.

On March 11, the FAA received additional ADS-B data. The data was analyzed and reviewed on March 12 and through the early hours of March 13. Also on March 13, physical evidence from the crash site indicated that the aircraft was in a configuration that

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would have armed MCAS. The satellite ADS-B data from ET302, when compared with the Lion Air Flight Data Recorder (FDR) and physical data, indicated a potential causal link between the accidents. On March 13, with the potential relationship established between the two accidents, the FAA issued an Emergency Order of Prohibition (see Appendix A) grounding 737 MAX aircraft.

As of this report, KNKT has issued its final JT610 accident report. The ET302 accident investigation by the Aircraft Accident Investigation Bureau of Ethiopia is still underway. This report reflects the FAA’s review of the JT610 final report and of the preliminary and interim reports from the ET302 investigation.

The FAA reviewed the contributing factors and available data from both accidents and reviewed the existing MCAS design to identify issues and determine the actions needed to safely operate the 737 MAX. The FAA determined that the aircraft, flightcrew, and maintenance issues summarized in the chart below must be addressed. The chart also includes a summary of the required corrective actions, all of which are further explained in the body of this report.

Identified Issue	FAA Determination of Issues That Must Be Addressed	Corrective Action*
<p>Safety Item #1: USE OF SINGLE ANGLE OF ATTACK (AOA) SENSOR: Erroneous data from a single AOA sensor activated MCAS and subsequently caused airplane nose-down trim of the horizontal stabilizer.</p>	<p>Ensure that an erroneous signal from a failed single AOA sensor meets all FAA requirements, does not prevent continued safe flight and landing, and specifically that it does not generate erroneous MCAS activation.</p>	<p>Boeing updated the Flight Control Computer (FCC) software to eliminate MCAS reliance on a single AOA sensor signal by using both AOA sensor inputs and changing flight control laws to safeguard against MCAS activation due to a failed or erroneous AOA sensor.</p>
<p>Safety Item #2: MCAS RESET GENERATES REPETITIVE MCAS COMMANDS: When a continuous erroneous high AOA sensor value exists, the MCAS control law uses pilot release of the electric trim switch to reset MCAS activation. Once reset, the MCAS system will make another airplane nose-down stabilizer trim command after five seconds. This scenario repeats each time MCAS makes a command and the pilot makes an electric trim command of any duration and releases the trim switch.</p>	<p>Ensure that if MCAS is activated, it will generate a single nose-down command activation.</p>	<p>Boeing changed flight control laws to ensure that MCAS will not command repeated movements of the horizontal stabilizer. The revised flight control laws permit only one activation of MCAS per sensed high-AOA event. Any subsequent activation of MCAS would only be possible after the airplane returns to a low-AOA state.</p>

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Identified Issue	FAA Determination of Issues That Must Be Addressed	Corrective Action*
<p>Safety Item #3: MCAS TRIM AUTHORITY: All MCAS commands were incremental commands, which moved the horizontal stabilizer a fixed amount, regardless of the current position of the stabilizer. Therefore, multiple MCAS commands resulted in a significant horizontal stabilizer mistrim condition, which the flightcrew could not counter using only elevator control.</p>	<p>Ensure that if MCAS is erroneously activated, the MCAS system preserves the flightcrew's ability, using basic piloting techniques, to control the airplane after the activation.</p>	<p>Boeing changed flight control laws to include a limit for MCAS commands. The MCAS will stop commanding stabilizer movement at a point that preserves enough elevator movement for sufficient pilot control of aircraft pitch attitude for current operating conditions.</p>
<p>Safety Item #4: FLIGHTCREW RECOGNITION AND RESPONSE: FDR data from both accidents show that the flightcrews were unable to effectively manage the stabilizer movement and multiple flight deck effects that resulted from the single AOA sensor failure.</p>	<p>Ensure that after any foreseeable failure of the stabilizer system, safe flight is not dependent on the timeliness of the flightcrew performing a non-normal procedure.</p>	<p>In addition to the software changes noted in Safety Items #1, #2 and #3, Boeing revised or added eight non-normal flightcrew procedures to the Airplane Flight Manual and proposed additional training. The flightcrew procedures and the revised pilot training provide the pilot additional information to recognize and respond to erroneous stabilizer movement and the effects of potential AOA sensor failures.</p>
<p>Safety item #5: AOA DISAGREE: The AOA DISAGREE alert message on the Primary Flight Display is not functional unless the AOA indicator option was chosen by the airline. This alert message is intended to be standard on all 737 MAX airplanes.</p>	<p>Ensure 737 MAX Display System (MDS) software will alert the flightcrew with the AOA DISAGREE message if there is disagreement between the Left and Right AOA Sensors.</p>	<p>Boeing has revised the AOA DISAGREE alert message implementation to achieve the original design intent to be standard on all 737 MAX aircraft.</p>
<p>Safety Item #6: OTHER POSSIBLE FCC STABILIZER RUNAWAY FAILURES: A comprehensive review of the integrated System Safety Analysis (SSA) of MCAS by Boeing and the FAA identified an extremely remote FCC failure condition that required timely pilot intervention to ensure continued safe flight and landing.</p>	<p>Ensure that after any foreseeable failure of the stabilizer system, continued safe flight and landing is not dependent on the timeliness of the flightcrew performing a non-normal procedure.</p>	<p>Boeing implemented a cross FCC Trim Monitor, which can effectively detect and shut down erroneous stabilizer commands from the FCCs. This makes continued safe flight and landing for this type of failure not dependent on pilot reaction time.</p>

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Identified Issue	FAA Determination of Issues That Must Be Addressed	Corrective Action*
<p>Safety Item #7: MAINTENANCE PROCEDURES RELATED TO THE MCAS: The KNKT final report for Flight JT610 shows several maintenance actions related to repair and installation of a replacement AOA sensor. <i>“The replacement AOA sensor that was installed on the accident aircraft had been mis-calibrated during an earlier repair. This mis-calibration was not detected during the repair. The investigation could not determine that the installation test of the AOA sensor was performed properly. The mis-calibration was not detected.”</i></p>	<p>Revise the component maintenance instructions for the AOA sensor to ensure proper AOA sensor calibration during repair procedures.</p> <p>As part of the KNKT investigation of Flight JT610, the FAA evaluated existing Boeing Airplane Maintenance Manual (AMM) procedures for AOA sensor installation. The KNKT investigation (Reference section 12.3) verified these existing procedures for AOA sensor installation will correctly identify a mis-calibrated AOA sensor.</p>	<p>The Collins Component Maintenance Manual (CMM) for the AOA sensor was revised to include a final independent check to ensure the repair has not introduced a bias.</p> <p>To ensure that each airplane's two AOA sensors are functioning properly upon return to service, operators must perform AOA Sensor System Tests on each airplane prior to its return to service. This test uses a fixture to position the AOA vane and verify that the reading provided by each AOA sensor is accurate.</p>

Immediately following the first accident and after issuing the Emergency AD, the FAA instructed Boeing to address the flight control software. After the second accident, the FAA directed Boeing to address the common link between the two accidents. The FAA used accident data and expert analysis to target the software changes necessary to address the causes and factors that contributed to both accidents.

Boeing’s initial efforts focused on changing the activation and reset criteria for the MCAS control laws, which involved extensive pilot assessment in the simulator. As a result of continuous review and testing of Boeing’s proposed software design changes, the FAA took a broader approach to how MCAS functions within the Speed Trim System (STS). The result is an extensive set of improvements to MCAS, with increased checks and balances at the system level. The updated FCC software minimizes dependence on pilot action and the effect of any potential single failure.

Summary of Changes to Aircraft Design and Operation

Both the 737 MAX and the 737 NG include an STS that automatically moves the horizontal stabilizer in response to changes from trimmed airspeed while in manual flight. The MCAS function is part of the STS. The STS provides increased aircraft speed stability as required by the FAA’s certification regulations — namely 14 CFR 25.173, Static Longitudinal Stability — so the pilot has a positive feel (pull- or push-force) when operating the aircraft faster or slower than where it is trimmed within the normal flight envelope. A key difference between the 737 MAX and its 737 NG predecessor is the 737 MAX’s larger and more powerful LEAP-1B engines. Because of their size, the engines are installed higher and farther forward than the engines on the 737 NG.

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The 737 MAX was designed to handle and feel the same to the pilot as the 737 NG. Without the MCAS function, in some small areas of the flight envelope — such as approaching a stall and during higher g-force maneuvering — the new engines contribute to the control column feeling lighter in the 737 MAX than the regulations allow. These are not areas of the flight envelope in which the airplane normally operates. However, FAA regulations - specifically 14 CFR 25.143, 25.201, 25.203, 25.251, and 25.255 - still require the control column to have a higher pull-force feel in these flight regimes than would exist on the 737 MAX without the added stability from the STS and MCAS function.

For the FAA to certify the 737 MAX, the original design had to meet FAA requirements for control force feel when maneuvering or deviating significantly from trimmed equilibrium. The aircraft manufacturer is responsible for making design decisions and showing compliance to applicable regulations. In this case, Boeing elected to include an additional flight control law in the STS, which is part of the flight control software that provides required control force feel to the pilot.

This flight control law, or MCAS, enhances the feel of the column forces in manual flight, and is only operative with flaps up. MCAS provides signals to move the horizontal stabilizer at elevated angles of attack to compensate for the aerodynamic effects of the 737 MAX's larger and more forward-located engines, resulting in the required column feel to the pilot.

Duration of the MCAS command is a function of AOA and airspeed. At higher airspeeds, flight control surfaces are more effective than at lower airspeeds. Therefore, a smaller MCAS command at higher airspeed has the same effect as a larger MCAS command at low speeds. Without MCAS, the 737 MAX would not meet FAA's regulatory requirements.

Boeing proposed multiple updates to the MCAS function to address Safety Item #1: USE OF SINGLE ANGLE OF ATTACK (AOA) SENSOR, Safety Item #2: MCAS RESET GENERATES REPETITIVE MCAS COMMAND and Safety item #3: MCAS TRIM AUTHORITY in the previous chart. The MCAS activation software now includes a maximum limit of one nose-down stabilizer activation during a single elevated AOA event and cannot be reset by pilot activation of the electric trim switches. An AOA sensor monitor was added to prevent MCAS from using an AOA input if it differs from the other AOA input by more than 5.5 degrees. Boeing incorporated a maximum command limit to disable the MCAS and speed trim operations if the stabilizer position exceeds a reference position. This limit ensures sufficient elevator control is available to provide maneuvering capability using control column inputs alone.

Additional Changes Related to the Flight Control Software Update.

An additional software change provides cross FCC monitoring to provide additional protections against MCAS malfunctions or any other erroneous FCC-generated stabilizer trim command, and to address Safety Item #6: OTHER POSSIBLE Flight Control Computer (FCC) STABILIZER RUNAWAY FAILURES. This monitoring is designed to provide additional

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protection against erroneous trim commands caused by possible — but unlikely — failures, such as a fault within a single integrated circuit in the FCC.

The software update to both primary flight displays (MAX Display System) includes improved AOA DISAGREE annunciation logic, which addresses Safety Item #5: AOA DISAGREE alert message. The AOA DISAGREE annunciation is now always enabled, regardless of the AOA gauge option. An additional improvement locks the AOA DISAGREE annunciation when the aircraft is below 400 feet in altitude.

To reflect the various updates, Boeing proposed eight new or changed procedures in the Airplane Flight Manual (AFM): SPEED TRIM FAIL, Airspeed Unreliable, AOA DISAGREE, ALTITUDE (ALT) DISAGREE, Runaway Stabilizer, Indicated Airspeed (IAS) DISAGREE, Stabilizer Trim Inoperative, and STAB OUT OF TRIM. These changes, along with certain changes to training (see below) address Safety Item #4: FLIGHTCREW RECOGNITION AND RESPONSE.

As a result of the design work to change the MCAS behavior and the subsequent review of the Integrated Speed Trim System Safety Analysis, the FAA required an additional evaluation of the related aircraft systems for all flight phases and system modes. The FAA evaluated Boeing's determination of a non-compliance with FAA wire separation requirements. As a result, Boeing developed changes to the system, which include physical separation of existing wires and/or routing of new wires in multiple areas of the Main Electric Trim and Auto Trim system.

Training Enhancements

The 737 MAX Joint Operations Evaluation Board (JOEB) concluded evaluation activities at London's Gatwick Airport on September 22, 2020. The JOEB included civil aviation authorities and airline flightcrews from the United States, Canada, Brazil and the European Union. The civil aviation authorities and industry pilots selected for participation completed all scheduled tasks as planned. The JOEB determined that all design changes applicable to the 737 MAX are operationally suitable. The Board's evaluations also included assessments of Boeing's proposed differences training and return to service training. The JOEB, through evaluations of multiple crews from a globally diverse pilot group, determined that the proposed training by the applicant was acceptable. The FAA posted the 737 Flight Standardization Board (FSB) report, revision 17, for public comment on October 6, 2020. The comment period closed on November 2, 2020. After considering the comments received, the FAA published the final version of the 737 FSB report, revision 17, on November 18, 2020. This revision adds training requirements for the MCAS, Autopilot Flight Director System (AFDS) enhancements, and additional Special Emphasis Training. The FAA added Appendix 7 to delineate 737 MAX ground and flight training necessary to operate the 737 MAX modified with the new FCC software. You can view the final report on [this page](#).

Compliance Activity

The FAA retained all compliance findings for its review of the certification plans for the MCAS design change and the 737 MAX Display System software design change. This includes, but is not limited to, all test plans and reports associated with simulator and flight testing, all system safety analyses, the Plan for Software Aspects for Certification and Software Accomplishment Summary, and Service Bulletins.

Boeing demonstrated compliance with software development assurance (DA) requirements for the 737 MAX Enhanced Digital Flight Control System (EDFCS) in accordance with FAA and European Union Aviation Safety Agency (EASA) processes. The software DA process defines how Boeing develops, validates, verifies and manages software functional requirements. Boeing demonstrated requirements traceability from the design level requirements to the software requirements at the supplier level and back. Boeing also prepared a System Safety Analysis (SSA) that supports the FAA's review of these requirements. Data from the simulator cab test and flight test were used by Boeing, and evaluated by the FAA, to determine compliance in the event of an erroneous elevated AOA event or a hypothetical single FCC integrated circuit failure. Boeing and FAA analysis and tests demonstrated acceptable performance of software changes, such as the MCAS activation/resynchronization logic, AOA split vane monitor, and MCAS maximum command limit changes.

For human factors compliance, a variety of qualitative regulations address safety aspects of how humans recognize and react to multiple situations in flight and set the basis for the evaluation. These include 14 CFR 25.671, 25.672, 25.1302, 25.1309, 25.1322 and 25.1523. These aspects include the system changes with the updated MCAS function, change in the autopilot disconnect logic at the onset of the stall warning (stick shaker), and the integrated flight deck with the revised AFM procedures (checklists). Boeing and the FAA conducted multiple focused evaluations in an engineering simulator to validate the analysis of the design to the requirements. The evaluations included two-person flightcrews of Boeing pilots and pilots selected from airlines operating the 737 MAX. Selections were based on the pilots' employment with a U.S. or foreign air carrier, licensing level, experience level, and crew position. The selected crews were intended to be a representative cross-section of pilots expected to operate the 737 MAX. The FAA evaluated Boeing's human factors analysis of the change to the MCAS function that shows crew workload is within capabilities of a two-pilot flightcrew. The evaluation was supported by FAA observations and engineering simulator evaluations completed as part of the human factors evaluations.

The FAA is aware of concerns over the potential role of stabilizer trim wheel forces during the accidents and therefore required an analysis and test of these forces. Boeing used the results of the analysis and test to show that the system is compliant with FAA and EASA requirements up to maximum operating speeds. Simulator predictions validated by Boeing flight testing, and overseen by the FAA, were used to calculate the required trim wheel

forces and to further validate the existing engineering model. A mockup of the stab trim wheels was used to measure the force capability of appropriate pilots.

MCAS is designed to function when the airplane has a high angle of attack, such as when approaching stall. The FAA required an assessment of any impact, by the MCAS function, to stall identification and basic airplane stall characteristics. Boeing and the FAA conducted an extensive matrix of testing to confirm that basic airplane stall characteristics comply both with and without STS/MCAS operation.

During the original certification of the 737 MAX and again after the accidents, the FAA required Boeing to assess potential failures of the flight control system, as well as potential flightcrew responses to those failures. The FAA evaluated Boeing's assessment of flightcrew alerting and found that it complies with regulatory requirements. The FAA's holistic evaluation of the alerting system considered improvements to the system design, new flightcrew procedures, and the revised pilot training.

System Safety Analysis

The FAA evaluated Boeing's preliminary individual safety assessments on the flight control system and stabilizer showing that the designs of these systems meet all reliability and integrity safety requirements (see section 8.3.3 of the report). The FAA reviewed the final safety assessments to determine if there are any substantive changes from the preliminary safety assessment. Assessments include Failure Mode Effects Analysis, Functional Hazard Assessment, and Fault Tree Analysis. In addition to the individual safety assessments, Boeing prepared an Integrated Speed Trim Safety Analysis with an emphasis on the MCAS, including upstream and downstream interfaces. The FAA's review of the SSA included an evaluation of Boeing's STS design changes to determine if any STS failure modes rely on pilot reaction times to maintain safe operation of the aircraft. The FAA concluded through its review of the SSA, which was validated by Boeing through extensive failure modes testing in simulators that no STS failure modes rely on exceptional piloting skills or immediate pilot actions. The FAA review of the SSA also included an evaluation of Boeing's STS design changes to determine if any STS functionality was vulnerable to other single-point failures. The FAA concluded that no other single-point failures are evident in the STS.

Return to Service

The FAA rescinded the Emergency Order of Prohibition to allow the 737 MAX to return to service based on completion of the following actions:

- FAA approval of the amended aircraft design.
- Issuance of the AD that mandates specific actions that owners or operators must take to correct the unsafe condition.

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Additionally, the following conditions are prerequisites to resuming operations in the U.S.:

- For previously delivered 737 MAX airplanes, owner/operators must incorporate all FAA-mandated design changes and maintenance actions.
- For any future delivered 737 MAX airplanes, Boeing is required to incorporate the same mandatory actions.

All US air-carrier pilots must complete the 737 MAX special training described in the 737 FSB report before serving in a 737 MAX airplane.

The FAA will issue a CANIC for the 737 MAX that provides information to the global aviation community on a comprehensive set of actions that must be taken by owner/operators to ensure a safe return to service. The FAA will issue the CANIC before it issues an AD containing mandatory continued airworthiness information (MCAI). As other CAAs consider returning the 737 MAX to service in their jurisdictions, the FAA strongly recommends:

- CAAs with 737 MAX aircraft on their respective registries should mandate the pilot training identified in the 737 MAX FSB report as a minimum starting point.
- Each State of Registry is responsible for the continued airworthiness and continued operational safety (COS) of aircraft on its registry. Accordingly, all States of Registry should adopt the final FAA AD and mandate the same changes in their own systems.

Conclusion

Through a thorough, transparent, and inclusive process, the FAA has determined that Boeing's proposed changes to the 737 MAX design, flightcrew procedures and maintenance procedures effectively mitigate the airplane-related safety issues that contributed to the Flight 610 and Flight 302 accidents. The FAA further determined that the proposed design change also address safety concerns beyond those that the accident investigations identified. This report does not address other safety issues that might have contributed to the accidents but are not related to airplane design. This includes the airline maintenance practices, the aircraft operators' compliance posture, and pilot training effectiveness. The FAA believes recommendations related to these other potential contributing factors should be addressed by the appropriate organizations.

Furthermore, the FAA and international aviation authorities evaluated Boeing's proposed flightcrew training through the FAA's Flight Standardization Board process. The FAA issued a Boeing 737 Flight Standardization Board Report documenting the results of the operational evaluation.

1. Purpose of Final Summary

This report provides a detailed technical account of the lessons learned since the two fatal accidents involving the 737 MAX aircraft, as well as the actions the FAA took to ensure its safe return to service. As the State of Design agent, the FAA is providing this report to all States of Registry to assist in their understanding of how the agency identified and is addressing the safety issues affecting the 737 MAX.

2. Introduction

The FAA has a longstanding commitment to transparency, continuous improvement and a global exchange of safety-related information that encourages increased aviation safety worldwide. The U.S., as the State of Design for the 737 MAX and signatory on the Convention on International Civil Aviation (Chicago Convention), is obliged to provide all States of Registry for the 737 MAX with the safety information they need to oversee the safe operation of the aircraft within their national systems. The ultimate decision to return the 737 MAX to service rests with each State of Registry.

The FAA's goal is to provide the global community the path by which the 737 MAX airplanes meet FAA safety standards and are safe for operation before they are returned to service.

On October 29, 2018, Lion Air Flight 610 (JT610), a Boeing 737 MAX, crashed shortly after takeoff in Jakarta, Indonesia. All 189 people on board perished. On March 10, 2019, Ethiopian Airlines Flight 302 (ET302), also a Boeing 737 MAX, crashed shortly after takeoff in Addis Ababa, Ethiopia, killing all 157 people on board.

In the days immediately following the Ethiopian Airlines tragedy, the 737 MAX worldwide fleet was grounded. On March 13, 2019, the FAA issued an Emergency Order of Prohibition (see Appendix A) grounding Boeing 737 MAX airplanes (737 MAX). A CANIC followed the Emergency Order.

The Indonesian KNKT completed and published the JT610 accident report. The ET302 accident remains under investigation by the Ethiopian accident investigation bureau. The FAA provided technical support to both investigations. The agency's technical support, along with the reports that the investigative bodies have issued, enabled the FAA to work with Boeing to identify both interim and long-term actions to address the safety of the 737 MAX.

Safe operation of all aircraft, regardless of where they operate, depends on the proper functioning of the entire aviation system. To provide the desired level of safety, all stakeholders must embrace a culture that includes the open exchange of information. At the tactical level, aviation safety also includes — among many other elements — the design and eventual operation of aircraft, as well as proper training and maintenance.

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In fulfilling the FAA's State of Design responsibilities, the FAA expects that the changes to the design, operation, training and maintenance of the 737 MAX outlined in this report will effectively mitigate the airplane-related safety issues that contributed to the JT610 and ET302 accidents. Since the accidents, the FAA has worked with the International Civil Aviation Organization (ICAO), CAAs, aviation community stakeholders, and Boeing to identify and mitigate all safety concerns and vulnerabilities, including unsafe conditions. This work includes review, analysis, testing, and evaluation of the proposed software updates for the 737 MAX series aircraft, as well as updated operational documentation (flightcrew and maintenance procedures), and enhanced flightcrew training.

Open and continuous communication with the agency's international partners is essential to global aviation safety. It is in this spirit that the agency regularly consulted with its counterpart CAAs. Events such as Directors' General meetings and webinars held periodically throughout this process demonstrate the FAA's commitment to transparency.

The agency will also provide the international community with mandatory continued airworthiness information (MCAI) as required by the ICAO Convention on International Civil Aviation, Annex 8.

As stated throughout the certification process, the FAA will approve the 737 MAX for return to service only after determining it to be safe for operation.

In addition to identifying the relationship of Boeing's design changes to the causes of the accidents, the report highlights how the FAA certified the design changes, including operational, training, and maintenance evaluation of Boeing's proposal. The report also provides details on the steps the FAA will take to return the 737 MAX to service and to rescind the Emergency Order of Prohibition that limited the operation of these airplanes.

Consistent with ICAO Annex 8, the FAA as the State of Design has the authority and obligation to issue an AD to address unsafe conditions when appropriate. The FAA issued an AD, which mandates software and Airplane Flight Manual (AFM) changes, as well as other corrective actions. In addition, the revised 737 FSB report identifies relevant required training. The agency hopes this report will assist the agency's partners in their respective decision-making processes on returning the aircraft to service.

3. FAA Continued Operational Safety Process

The FAA Continued Operational Safety (COS) process is established through FAA Order 8110.107A, *Monitor Safety/Analyze Data (MSAD)*. The FAA uses the COS process to evaluate information received from operations to support its decisions for COS of the U.S. operational fleet, as well as the global fleet for which the U.S. has State of Design responsibility.

The COS process informs FAA actions to correct hazards in airworthiness, operational procedures, training or maintenance. MSAD is a data-driven COS methodology that provides a risk-based approach for safety assurance and safety risk management. MSAD

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supports aviation products throughout their life cycle. The process uses product-defined hazard criteria to reveal potential hazards from aviation safety data. In addition, MSAD establishes a causal analysis approach. This approach may identify underlying contributing factors, such as process breakdowns, which the agency then communicates to the appropriate stakeholder.

The MSAD process is heavily based on industry best practices. MSAD builds a safety risk management model that provides a data-driven approach. This approach has evolved over many decades of experience and research by the FAA, in collaboration with the aviation industry and global regulators, and through partnerships with academia and other government agencies.

Figure 1 below shows a generalization of the process the FAA uses. It should be noted that FAA MSAD guidance provides flexibility in how to approach any particular safety issue. This allows the FAA subject matter experts and management the freedom to bypass steps in the process based on unique circumstances. Flexibility in the process assures that safety — not rigid procedures — drives the agency’s actions. Further details of the FAA’s process can be found in Appendix B.

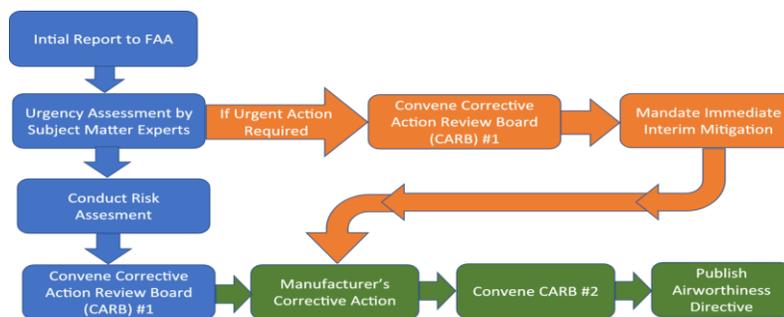


FIGURE 1 COS PROCESS GENERALIZATION

4. 737 MAX Accidents and the FAA’s Continued Operational Safety Actions

4.1 JT610 Emergency Airworthiness Directive

This section describes the FAA’s actions in response to the accident involving Lion Air Flight 610 and the pertinent details found in the Final KNKT Aircraft Accident Investigation Report, Lion Air Boeing 737 MAX registered as PK-LQP, dated October 29, 2019.

On October 29, 2018, JT610 crashed shortly after takeoff in Jakarta, Indonesia. The KNKT (the accident investigation board in Indonesia) recovered the Flight Data Recorder (FDR). With assistance from Australia and Singapore, the KNKT conducted a preliminary FDR data analysis and shared it with the FAA on November 4, 2018. The FDR data analysis showed Angle of Attack (AOA) data input anomalies sent to the flight control computer

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(FCC), unusual movement of the horizontal stabilizer trim system, and multiple flight deck effects.

FAA and Boeing evaluations determined that airplane nose-down and stabilizer trim movement was consistent with repeated activation of the Maneuvering Characteristics Augmentation System (MCAS) flight-control law (See Section 6 for a description of MCAS function).

The review by the FAA and Boeing of the FDR data showed that the flight immediately prior to the accident flight also experienced anomalous AOA vane behavior and corresponding stabilizer movement. The data indicated the flightcrew correctly executed the horizontal stabilizer runaway checklist and used the stab cut-out switches to shut down the horizontal Stabilizer Trim Motor (STM) and therefore disable MCAS. This action enabled the crew to continue safe flight and landing to their planned destination airport. The FAA conclusion from this analysis indicated that an average crew with no prior awareness could sort out the failure scenario and could correctly mitigate the failure using existing procedures.

The FAA conducted preliminary risk assessments on November 5, 2018, and determined urgent mandatory action was needed to mitigate the unintended movement of the horizontal stabilizer trim system in response to the erroneous AOA vane input. The FAA reviewed and modified Boeing's proposed pilot interventions for erroneous MCAS activations. Based on this review, the FAA decided to mandate these interventions in an Emergency AD (see Appendix C) to address this potential nose-down trim, which could make the airplane difficult to control and could lead to excessive nose-down attitude, significant altitude loss, and possible impact with terrain.

On November 6, 2018, the FAA issued a CANIC (see Appendix D) which notified Civil Aviation Authorities (CAA) around the world that the FAA intended to issue an Emergency AD to correct an unsafe condition on the 737 MAX.

On November 7, 2018, the FAA issued Emergency AD 2018-23-51. The AD was an interim action. The FAA planned further terminating action based on what the agency and Boeing learned from further investigating the JT610 accident cause.

4.2 ET302 Emergency Order of Prohibition

This section describes the FAA actions following the accident involving Ethiopian Airlines Flight 302 ET302 accident and the pertinent details found in the *Accident Investigation Preliminary Report Ethiopian Airlines Group, B737 MAX registered as ET-AVJ*, dated March 2019.

On March 10, 2019, ET302 crashed shortly after takeoff in Addis Ababa, Ethiopia. Partial data (e.g., altitude, airspeed and vertical speed) was available from a land-based Automatic Dependent Surveillance—Broadcast (ADS-B) system. On March 11, 2019, the FAA issued a CANIC (see Appendix D) indicating the FAA was actively supporting the

investigations. The FAA received additional satellite-based ADS-B data on March 11. The data was analyzed and reviewed on March 12 through the early hours of March 13. Also on March 13, physical evidence from the crash site indicated the aircraft was in a configuration that would have armed MCAS. The physical data, and the satellite ADS-B data from ET302 when compared with the Lion Air FDR data, provided a potential link between the accidents.

Once the potential relationship between the two accidents was established, the FAA on March 13, 2019, issued an Emergency Order of Prohibition (see Appendix A), grounding the 737 MAX aircraft.

5. Identification of Design Aspects for Boeing to Address

As of the date of this report, the JT610 final accident report has been issued and the ET302 accident investigation is ongoing. The KNKT, with support from the National Transportation Safety Board (NTSB) and the FAA, documented the contributing factors that led to the JT610 accident. This report includes the FAA's review of the KNKT recommendations in the JT610 final report.

The ET302 accident investigation has not yet published a final report. The FAA reviewed the preliminary and interim reports from the ET302 investigation and affirms that all preliminary recommendations relative to the 737 MAX return to service (RTS) have been addressed. Because the ET302 report is interim, the FAA has not included the ET302 report recommendations in this report. The FAA reviewed the contributing factors and available data from both accidents and reviewed the existing MCAS design to identify issues and determine the actions necessary to safely operate the 737 MAX. The FAA has determined that MAX operators must address the aircraft, flightcrew and maintenance issues identified in the chart in section 5.2 of this report. The chart also includes a summary of the corrective actions, which are further explained in the remainder of this report.

5.1 Considerations During Corrective Action Development

Immediately after the first accident and after issuing the Emergency AD, the FAA instructed Boeing to address the flight-control software. Following the second accident, the FAA directed Boeing to address the common link between the two accidents. The FAA used accident data and expert analysis to target the software changes necessary to address the causes and factors that contributed to both accidents.

Initial efforts focused on changing the activation and reset criteria for the MCAS control laws, which involved extensive pilot assessment in the simulator.

Later, as a result of continuous review and testing of Boeing's proposed software design changes, the agency took a broader approach to how the MCAS functions within the STS. The result is a more extensive set of improvements to the MCAS function, increasing

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checks and balances at the system level. The Speed Trim System’s updated software minimizes dependence on immediate pilot action and the effect of any potential single failure.

The MCAS-related FCC software update is not applicable to the 737 NG because the 737 NG does not include MCAS and is therefore not included in the FAA certification efforts in this matter. However, Boeing will also review ancillary changes that can enhance the 737 NG. The FAA will work with Boeing to ensure that any issues related to the 737 MAX design change that may apply to the 737 NG will be addressed as applicable.

5.2 Issues

Identified Issue	FAA Determination of Issues That Must Be Addressed	Corrective Action*
<p>Safety Item #1: USE OF SINGLE ANGLE OF ATTACK (AOA) SENSOR: Erroneous data from a single AOA sensor activated MCAS and subsequently caused airplane nose-down trim of the horizontal stabilizer.</p>	<p>Ensure that an erroneous signal from a failed single AOA sensor does not prevent continued safe flight and landing, and specifically that it does not generate erroneous MCAS activation.</p>	<p>Boeing updated the FCC software to eliminate MCAS reliance on a single AOA sensor signal by using both AOA sensor inputs and changing flight control laws to safeguard against MCAS activation due to a failed or erroneous AOA sensor.</p>
<p>Safety Item #2: MCAS RESET GENERATES REPETITIVE MCAS COMMANDS: When a continuous erroneous high AOA sensor value exists, the MCAS control law uses pilot release of the electric trim switch to reset MCAS activation. Once reset, the MCAS system will make another airplane nose-down stabilizer trim command after five seconds. This scenario repeats each time MCAS makes a command and the pilot makes an electric trim command of any duration and releases the trim switch.</p>	<p>Ensure that if MCAS is activated, it will generate a single nose-down command.</p>	<p>Boeing changed flight control laws to ensure that MCAS will not command repeated movements of the horizontal stabilizer. The revised flight control laws permit only one activation of MCAS per sensed high-AOA event. Any subsequent activation of MCAS would only be possible after the airplane returns to a low-AOA state.</p>
<p>Safety Item #3: MCAS TRIM AUTHORITY: All MCAS commands were incremental commands, which moved the horizontal stabilizer a fixed amount, regardless of the current position of the stabilizer. Therefore, multiple MCAS commands resulted in a significant horizontal stabilizer mistrim condition, which the flightcrew could not counter using only elevator control.</p>	<p>Ensure that if MCAS is erroneously activated, the MCAS system preserves the flightcrew’s ability, using basic piloting techniques, to control the airplane after the activation.</p>	<p>Boeing changed flight control laws to include a limit for MCAS commands. The MCAS will stop commanding stabilizer movement at a point that preserves enough elevator movement for sufficient pilot control of aircraft pitch attitude for current operating conditions.</p>

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Identified Issue	FAA Determination of Issues That Must Be Addressed	Corrective Action*
<p>Safety Item #4: FLIGHTCREW RECOGNITION AND RESPONSE: FDR data from both accidents show that the flightcrews were unable to effectively manage the stabilizer movement and multiple flight deck effects that resulted from the single AOA sensor failure.</p>	<p>Ensure that after any foreseeable failure of the stabilizer system, safe flight is not dependent on the timeliness of the flightcrew performing a non-normal procedure.</p>	<p>In addition to the software changes noted in Safety Items #1, #2 and #3, Boeing revised or added eight non-normal flightcrew procedures to the Airplane Flight Manual and proposed additional training. The flightcrew procedures and the revised pilot training provide the pilot additional information to recognize and respond to erroneous stabilizer movement and the effects of potential AOA sensor failures.</p>
<p>Safety Item #5: AOA DISAGREE: The AOA DISAGREE alert message on the Primary Flight Display is not functional unless the AOA indicator option was chosen by the airline. This alert message is intended to be standard on all 737 MAX airplanes.</p>	<p>Ensure 737 MAX Display System (MDS) software will alert the flightcrew with the AOA DISAGREE message if there is disagreement between the Left and Right AOA Sensors.</p>	<p>Boeing has revised the AOA DISAGREE alert message implementation to achieve the original design intent to be standard on all 737 MAX aircraft.</p>
<p>Safety Item #6: OTHER POSSIBLE FCC STABILIZER RUNAWAY FAILURES: A comprehensive review of the integrated SSA of MCAS by Boeing and the FAA identified an extremely remote FCC failure condition that required timely pilot intervention to ensure continued safe flight and landing.</p>	<p>Ensure that after any foreseeable failure of the stabilizer system, continued safe flight and landing is not dependent on the timeliness of the flightcrew performing a non-normal procedure.</p>	<p>Boeing implemented cross FCC Trim Monitor, which can effectively detect and shut down erroneous stabilizer commands from the FCCs. This makes continued safe flight and landing for this type of failure not dependent on pilot reaction time.</p>
<p>Safety Item #7: MAINTENANCE PROCEDURES RELATED TO THE MCAS: The KNKT final report for Flight JT610 shows several maintenance actions related to repair and installation of a replacement AOA sensor. <i>“The replacement AOA sensor that was installed on the accident aircraft had been mis-calibrated during an earlier repair. This mis-calibration was not detected during the repair. The investigation could not determine that the installation test of the AOA sensor was performed properly. The mis-calibration was not detected.”</i></p>	<p>Revise the component maintenance instructions for the AOA sensor to ensure proper AOA sensor calibration during repair procedures.</p> <p>As part of the KNKT investigation of Flight JT610, the FAA evaluated existing Boeing AMM procedures for AOA sensor installation. The KNKT investigation (Reference section 12.3) verified these existing procedures for AOA sensor installation will correctly identify a mis-calibrated AOA sensor.</p>	<p>The Collins Component Maintenance Manual (CMM) for the AOA sensor was revised to include a final independent check to ensure the repair has not introduced a bias.</p> <p>To ensure that each airplane's two AOA sensors are functioning properly upon return to service, operators must perform AOA Sensor System Tests on each airplane prior to its return to service. This test uses a fixture to position the AOA vane and verify that the reading provided by each AOA sensor is accurate.</p>

6. MCAS System Description and Flight Deck Effects

The originally certified design of the MCAS control law enabled the system to activate repeatedly during manual flight (Autopilot OFF) and when the flaps are fully retracted. Once enabled, and if the airplane's AOA exceeded a threshold, MCAS provided the potential for multiple activations of the MCAS automatic airplane nose-down stabilizer trim commands if the pilot used the main electric trim switch during the high-AOA event.

The new design changes this behavior. Boeing modified the flight-control-law logic to ensure that MCAS activation cannot be reset and command repeated movements of the horizontal stabilizer. During an activation MCAS can be paused if the pilots use the electronic trim switches. MCAS will resume after the switches are released, but will only continue moving the horizontal stabilizer up to the maximum remaining command from the original activation appropriate for that airspeed. The revised flight control law logic will allow only one MCAS activation for each high-AOA event.

After the manual flight maneuver that created the high AOA and consequent single MCAS nose-down command, MCAS now makes an airplane nose-up (ANU) command to return the stabilizer to the pre-activation trim position upon returning to low AOA flight — if the pilot has not changed the trim.

If the pilot has changed the trim during the MCAS maneuver, MCAS will now return to the new reference stabilizer position set by the trim input. The MCAS flight-control law will be reset once the AOA falls sufficiently below the MCAS AOA threshold.

For example, in the original and the new versions, normal MCAS activation during manual flight would occur when the airplane is at a high AOA (such as during a high-speed tight-banked turn or low-speed approach to stall). During these maneuvers, the pilot may continue to pull back on the control column resulting in a higher AOA. To improve pitch stability, MCAS commands nose-down stabilizer. The result of the MCAS nose-down input makes the control column feel heavier as the pilot pulls back. This heavier feel complies with control-force requirements in FAA regulations.

After completing the tight turn and returning to level flight, the incremental stabilizer input made by MCAS during the high AOA condition is removed by MCAS.

The updated MCAS control law does not affect the attention, perception and reasonable decision making of the flightcrew because there are no changes in flight deck effects in nominal MCAS activation scenarios. For certain potential AOA failures, such as physical failure due to damage or a mis-calibration, the updated FCC software reduces crew workload by inhibiting MCAS activation and presenting the SPEED TRIM FAIL alert (which has no associated crew tasks).

Section 6.1 describes Boeing's design and functional changes that address Safety Item #1: USE OF SINGLE AOA SENSOR, Safety Item #2: MCAS RESET GENERATES REPETITIVE MCAS COMMAND and Safety item #3: MCAS TRIM AUTHORITY.

6.1 System Description

Both the 737 NG and the 737 MAX include a Speed Trim System that automatically moves the horizontal stabilizer in response to changes from trimmed airspeed while in manual flight for speed stability. The 737 MAX includes an additional pitch augmentation flight control law called MCAS, which affects pitch characteristics in manual flight, with flaps up and at elevated angles of attack, to compensate for the aerodynamic pitch effects associated with the 737 MAX's larger, more forward located engines. MCAS enables the 737 MAX to comply with FAA regulatory requirements for certain handling qualities and cannot be removed unless replaced with a comparable system. Boeing has not presented a comparable system so the need for MCAS remains.

The MCAS flight-control law is part of the Speed Trim System and is commanded by the FCC using data from sensors and other airplane systems. As a stability-augmentation system, MCAS automatically makes commands without pilot action. Either pilot can override MCAS commands to control the stabilizer by using the electric stabilizer trim switches on the control wheel. Additionally, flightcrews can set the STAB TRIM CUTOUT switches on the center control stand to CUTOUT to stop and disable MCAS.

The MCAS flight-control law becomes active when the airplane exceeds an AOA threshold that varies depending on Mach (airspeed). If activated by a high AOA, MCAS moves the horizontal stabilizer at a rate of 0.27 degrees per second, which is the same trim rate as Speed Trim with flaps down. The magnitude of the MCAS command is a function of Mach and angle of attack. At higher airspeeds, flight-control surfaces are more effective than at lower airspeeds. Therefore, a smaller MCAS command at higher airspeeds has the same effect as a larger MCAS command at lower speeds. At low Mach, when the stabilizer has lower effectiveness, the MCAS command can be up to the maximum of 2.5 degrees of incremental stabilizer movement. The MCAS flight control law is reset after the AOA falls sufficiently below the AOA threshold.

6.1.1 Overview of Updated MCAS Flight Control Laws

This section describes multiple updates within the MCAS function. The MCAS activation and resynchronization logic limits airplane nose-down stabilizer command during a single elevated AOA event. Once the AOA has been reduced, the system will return the stabilizer to a new reference trim position if the pilot activates electric trim while MCAS is making a command, which will account for any pilot trim input made during the MCAS command. An AOA split-vane monitor and middle-value select (MVS) have been added to prevent MCAS from using AOA inputs that differ from the other AOA input by more than 5.5 degrees. Boeing set the designed AOA input differential threshold of 5.5 degrees, based on electro-mechanical tolerances of the sensor and normal transient aerodynamic effects on the AOA sensors mounted on opposite sides of the fuselage during flight with flaps up. MVS logic has been added to the MCAS AOA signal processing to mitigate the potential hazard of undetected erroneous oscillatory AOA signal.

The AOA split-vane monitor threshold is large enough to allow for expected variations in AOA sensors but small enough to prevent MCAS activation due to erroneous AOA data. Forward column cutout switch interaction with the MCAS flight-control law is accounted for in order to accommodate trim interruption caused by potential activation of the cutout switch when returning the stabilizer to the trim position once the AOA has been reduced. A maximum command limit is incorporated that will disable MCAS and Speed Trim operations if the stabilizer position exceeds a reference position to ensure sufficient handling capability using control-column inputs alone. Detailed descriptions of these changes are provided below.

6.1.2 MCAS Activation/Resynchronization

During the original 737 MAX certification, Boeing demonstrated compliance with certain regulatory requirements for handling qualities by the functionality of MCAS. The airplane-level requirement to be compliant with those regulations remains, so the need for MCAS remains unchanged. The updated MCAS design retains the original MCAS activation thresholds for nominal conditions (i.e., absent sensor failures or pilot electric trim interaction). The revised MCAS activation criteria now include a requirement for the AOA to transition from a low AOA state (below the threshold) to a high AOA state (above the threshold) after the airplane is in the configuration and flight region where MCAS is utilized (flaps up and manual flight).

This single activation of MCAS will be limited to maximum of 2.5 degrees of airplane nose-down stabilizer motion (which is referred to as a single MCAS command). Reset of the MCAS system requires the AOA to transition sufficiently below the activation threshold. Since MCAS no longer resets after pilot activation of the electric trim switch, the five-second wait time following MCAS flight-control-law reset has been eliminated.

MCAS activation will be halted during the use of pilot electric stabilizer trim. Upon completion of the pilot's electric stabilizer trim inputs, MCAS may provide additional airplane nose-down stabilizer trim command if the AOA remains elevated and is continuing to increase. However, the airplane nose-down trim command cannot exceed a cumulative total of one MCAS delta stabilizer table value (maximum of 2.5 degrees as a function of Mach) for each high AOA event.

If pilot electric stabilizer trim is activated while above the AOA threshold, during the return to trim, MCAS would only command nose-up trim equivalent to the amount of nose-down trim that MCAS commanded following the last pilot electric trim input. This will move the stabilizer to the new reference trim position.

6.1.3 AOA Input Monitoring: Split Vane Monitor and Middle Value Select (MVS)

In the new design, each FCC receives left and right AOA sensor values from the left and right Air Data Inertial Reference Unit (ADIRU), respectively. The AOA values are transmitted from the ADIRUs to the FCCs via databuses.

During normal operation, accurate AOA values are transmitted over the databuses with a label that the values are considered "valid" by the ADIRU.

The AOA sensor electrical circuit includes wiring within the AOA sensor and wiring between the sensor and the ADIRU. A failure of that electrical circuit (e.g. open, short, etc.) will be detected by the ADIRU, and the ADIRU will not transmit data on the bus as being "valid." This failure scenario is referred to as a "detected failed" condition.

Certain AOA sensor failures are not related to degradation of the electrical circuit, and therefore are not detected by the ADIRU. These failures result in AOA values transmitted by the ADIRU as "valid" when, in fact, they are not correct. These outputs of the ADIRU are referred to as "valid erroneous" data. Examples of failures that result in erroneous data include a bent or broken AOA vane (e.g. due to a bird strike or ramp damage) or a mis-calibrated AOA sensor (e.g. JT610 scenario).

Each FCC receives and monitors the two AOA sensor inputs from the ADIRUs and determines which AOA value to use in the MCAS control-law calculations. AOA values are compared to one another by a split vane monitor and sent through a MVS algorithm.

The split vane monitor compares two valid AOA inputs and will use them only if the difference between the AOA values is less than or equal to 5.5 degrees. If the difference is greater than 5.5 degrees for a specified duration, the MCAS and Speed Trim functions will be disabled for the remainder of the flight. The split vane monitor becomes active after the flaps have been retracted during flight.

If the two valid signals are within the limits of the split vane monitor, they are put through the MVS algorithm. The MVS output is initialized at zero degrees. The MVS utilizes three numbers: the two current AOA values and the MVS output from the previous MVS determination. The algorithm determines the middle value of the three numbers by eliminating the highest and lowest values and using the remaining value (for example, for inputs 1, 2, and 4, the middle value is 2). The MVS algorithm is effective at minimizing the effect of a low amplitude oscillatory input value. The output of the MVS is used by the MCAS function within the FCC.

Effect of Erroneous AOA Value on MCAS — if the valid AOA value differs from the other valid AOA sensor value by more than 5.5 degrees for a specified duration the AOA values are considered erroneous, the split vane monitor will detect the failure and both the MCAS and Speed Trim functions will be disabled for the remainder of the flight. Activation of the split vane monitor will completely disable the STS (which includes both MCAS and Speed Trim System), will trigger a Master Caution indication, an illumination of the Flight Control (FLT CONT) annunciator, and an illumination of the SPEED TRIM FAIL light on the

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overhead panel. The Master Caution indication and the FLT CONT annunciator can be reset by pressing the MASTER CAUTION PUSH TO RESET button. The SPEED TRIM FAIL light will remain illuminated for the remainder of the flight. In addition, an accompanying maintenance item is recorded for the loss of MCAS and Speed Trim. The SPEED TRIM FAIL annunciation is shown in Figure 2.

Effect of Detected Failed AOA Sensor on MCAS — if a failed AOA circuit is detected, the FCCs will receive only one valid AOA value. The FCCs will utilize the valid AOA value to control MCAS. The Split Vane Monitor and MVS are not utilized.

During execution of the descent phase Master Caution recall checklist procedure, the SPEED TRIM FAIL light will be illuminated so the pilots will be aware of the condition. MCAS and Speed Trim will continue to operate using the available valid AOA signal. This design preserves the availability of Speed Trim and MCAS operation after a single detected failed AOA sensor.

A second independent failure during the same flight is considered to be extremely improbable. If a second independent failure affects the remaining AOA sensor, any resulting activation of MCAS would be limited to a single MCAS command (up to 2.5 degrees as a function of Mach).



FIGURE 2 SPEED TRIM FAIL ANNUNCIATION

6.1.4 Forward Column Cutout Interaction

It is possible for the forward column cutout switch to be activated while the pilot is pushing the control column forward during recovery from an elevated AOA condition. If MCAS is providing an airplane nose-up trim command to return the stabilizer to the trim position, activation of the forward column cutout switch will pause the stabilizer movement.

The forward column cutout interaction change accounts for the time during which the stabilizer is not moving due to column cutout. It finishes making the ANU trim command when the command is not being cutout, thus improving the precision with which MCAS returns the stabilizer to the trim position.

6.1.5 MCAS Maximum Command Limit

This change limits the total amount of airplane nose-down stabilizer movement MCAS can command if there are repeated MCAS activations. This ensures that the flightcrew will always have maneuver capability through control column inputs alone, enabling the flightcrew to maintain level flight without requiring use of the electric trim switches or the stabilizer trim cutout switches.

The redesigned FCC software compares the current stabilizer position to the stabilizer position that existed at initial MCAS activation. If the difference reaches a limit value that has been determined to preserve a maneuver capability with control column alone, then MCAS and Speed Trim operations are disabled for the remainder of the flight.

Flightcrew intervention is not required to activate the MCAS Maximum Command Limit or to disable the MCAS and Speed Trim operations. As discussed previously, when MCAS and Speed Trim are disabled, SPEED TRIM FAIL is annunciated and a maintenance item is recorded. Due to the MCAS changes previously discussed, this command limit is not expected to be used but provides an additional level of safety.

The maximum command-limit-reference-stabilizer position is reset by the FCC after one consecutive minute of the autopilot being engaged, or five consecutive minutes of manual flight below the MCAS AOA activation threshold, whichever comes first.

6.1.6 MCAS Engage and Stabilizer Trim Integrity Monitoring

MCAS Engage logic is computed in the FCC Lane 2 Central Processing Unit (CPU) and is communicated to the Lane 1 CPU. Lane 1 transmits the MCAS Engage signal which allows the FCC stabilizer trim to bypass the aft column cutout switch and sets the STM to run at the flaps-down FCC rate. In the updated FCC software, the Lane 1 CPU would only transmit MCAS Engage (as computed by the Lane 2 CPU) if the autopilot or Control Wheel Steering (CWS) are not engaged and the flaps are up. The purpose of this change is to reduce the likelihood of transmitting an erroneous MCAS Engage logic signal due to a Lane 2 CPU failure.

In addition, the updated FCC software replicates the mechanical column cutout functions using software. The Lane 1 CPU will inhibit transmittal of FCC Trim Up and Trim Down commands by the Lane 2 CPU if the commands are in opposition to the elevator surface position by an amount greater than that of the mechanical control column cutout switches. The Trim Down command will not be inhibited when the Lane 1 MCAS Engage discrete is True.

The magnitude of the software -column-cutout thresholds was set to a value outside the mechanical-control-column-cutout switches so it will not interfere with the mechanical switches while remaining effective if the mechanical switch fails to activate.

6.2 Cross-FCC Trim Monitor

The Cross-FCC Trim Monitor is a new feature to address Safety Item #6: OTHER POSSIBLE FCC STABILIZER RUNAWAY FAILURES and provides additional protection against erroneous FCC trim commands caused by postulated failures in the FCC Lane 2 CPU or I/O chips. This monitor is implemented in Lane 2 of the FCC.

While the FCCs are powered, each FCC continuously monitors the other FCC channel, except during dual-channel autopilot operation or when a Fail-operational configured airplane is performing an Autoland or automatic Go-Around. The FCC channel in which the autopilot or CWS is engaged, or which is the STS selected channel, is referred to as the operational FCC channel. The other FCC channel is referred to as the standby FCC channel.

The monitor compares the trim-up and trim-down command outputs from both FCCs with its own trim command calculation. The operational channel performs its normal stabilizer trim-command calculations for use by the monitor. The standby channel switches its data sources to use the same data as the operational channel to perform its stabilizer-command calculations for use by its monitor.

The following discussion applies to either the operational or standby channel:

If the stabilizer trim discrete outputs differ from the trim-command calculation in the local channel's monitor for a cumulative one second, as determined by an up/down counter, then the local channel will take control of STS (if it doesn't already have it), and send a discrete to Lane 1 of the foreign channel, indicating that the monitor has tripped. This will cause Lane 1 of the foreign channel to prevent transmittal of the foreign channel's Lane 2 stabilizer trim discrete outputs. If able, Lane 2 of the foreign channel will then set a SPEED TRIM FAIL discrete that will be observed during pilot execution of the descent phase Master Caution recall checklist procedure as described earlier in this section.

If the foreign channel's autopilot or CWS is engaged when the local channel's Lane 2 monitor has tripped, the autopilot or CWS will disconnect, accompanied by the autopilot disconnect warning aural and visual indications. Further attempts to engage the foreign channel's autopilot or CWS will be inhibited. Autopilot and CWS operation may still be available via the local channel.

In addition to the above, both channels will set the NO AUTOLAND discrete, causing NO AUTOLAND to be annunciated for the fail-operational configured airplanes. The channel whose monitor has tripped will also set the STAB OUT OF TRIM light to illuminate when on ground and below 30 knots. Illuminating the STAB OUT OF TRIM light on the ground

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ensures there is a maintenance action in the event the failed FCC channel is unable to report itself as failed using the SPEED TRIM FAIL light.

Cross-channel signals are added to ensure the Standby FCC is in MCAS operation any time the Operational FCC is in MCAS operation, reducing the number and duration of trim inhibits due to stab trim voting. The Standby FCC performs a reasonableness check on the Operational FCC signal to activate MCAS to ensure the activation difference is not due to a postulated FCC failure.

During Boeing research and development flight testing of the 737 MAX’s updated software, a STAB OUT OF TRIM light illuminated on the forward instrument panel. Boeing determined that the illumination of this light was caused by differences in input data between the FCCs. Boeing revised the proposed final FCC software to ensure that this indicator light only illuminates as intended.

To reduce nuisance trips of the Command Response Monitor due to stab-trim voting logic, the Standby FCC stabilizer-trim calculations have been aligned further by using Operational FCC elevator commands directly. The Command Response Monitor sets the STAB OUT OF TRIM light while autopilot is engaged. An additional monitor, the Autopilot Elevator Command Integrity Monitor, was added to ensure the integrity of using the elevator command signal in the Standby FCC stabilizer trim calculations, which can be corrupted by postulated FCC Lane 1 failures.

A power-up test was added to the FCC software to verify the availability of the FCC hardware switches used by the Cross-FCC Trim Monitor to disable the Lane 2 stabilizer trim discrettes and also check for the external trim wrap-arounds used by the Cross-FCC Trim Monitor to detect trim outputs of the other FCC. This test runs on power-up and after every landing.

A simplified schematic of the Cross-FCC Trim Monitor added in the updated FCC software is shown in Figure 3 below.

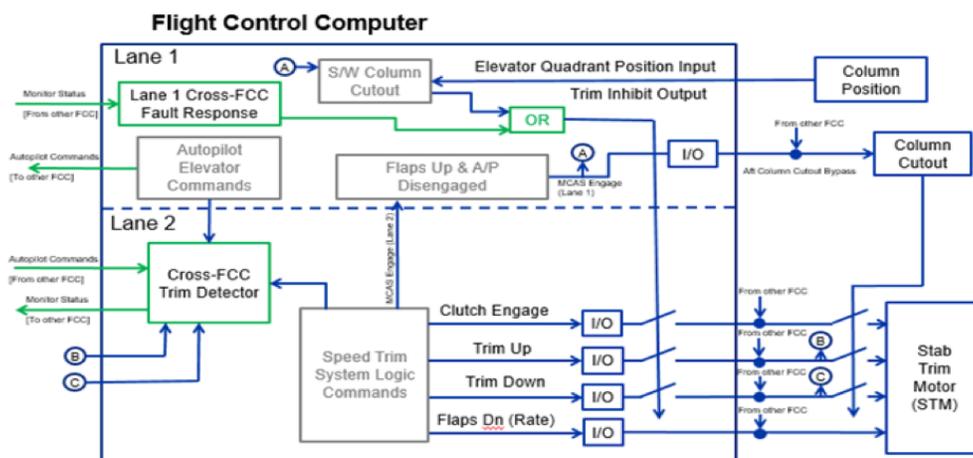


FIGURE 3 SIMPLIFIED SCHEMATIC OF THE UPDATED FCC SOFTWARE

6.3 Additional Flight Control System Enhancements

This section provides a description of additional autopilot changes Boeing included in the FCC software update. The changes are related to low airspeed conditions and affect how the autopilot functions and what the flight director will show on the Primary Flight Displays (PFDs). Although these changes are unrelated to the JT610 and ET302 accidents, Boeing elected to include them in this design change.

In earlier FCC software versions, the autopilot/flight director provided active-speed protection, or reversion to active-speed protection, in all pitch modes with the exception of Altitude Hold (ALT HLD), VNAV PATH (ALT HLD), Glideslope (G/S), Glidepath (G/P), Flare and, when flaps are at 15 or greater, Vertical Speed (V/S) and VNAV PATH (V/S). For modes that do not have active-speed protection, the autothrottle provides speed protection if engaged in speed mode. Additionally, an existing "AIRSPEED LOW" aural and visual alert, and a flashing amber airspeed callout box, are provided to alert the flightcrew in the event that the airspeed decreases into the amberband. For these modes, if the airspeed is allowed to decrease below stick-shaker speed, the FCC would continue to provide autopilot and flight-director commands to maintain the command path, including pitch-up commands if below the pitch target. Nose-up autotrim is inhibited when at or below stick-shaker speed.

The updated FCC software incorporates the following enhancements that improve the behavior of the autopilot/flight director in the event that the airspeed decreases into the amberband:

- Autopilot Automatic Stabilizer Trim Inhibit — During flaps-down autopilot operation, nose-up autotrim is inhibited at 3 knots below the amberband speed. During simulator cab evaluations, this change was shown to improve pitch characteristics at autopilot disconnect. No change to the inhibit logic was required for flaps-up autopilot operation due to the activation of MCAS upon autopilot disconnect.
- Autopilot Disconnect and Flight Director Bias Out of View (BOV) — For the autopilot/flight director modes that do not provide active-speed protection, with the exception of Flare mode, the autopilot will disconnect one second after stick shaker activation. Simultaneously, the pitch and roll-flight-director guidance will BOV, which means the vertical and horizontal flight-director bars will not be visible on the Primary Flight Display (PFD). Pitch and roll flight-director guidance will return when the airspeed returns to the top of the amberband. The roll mode will remain unchanged when the flight-director guidance resumes. The pitch mode will transition to Level Change (LVL CHG) if the previous mode was ALT HLD or VNAV PATH (ALT HLD), or will remain unchanged if the mode is G/S, G/P, V/S or VNAV PATH (V/S). Re-engagement of the autopilot is inhibited until the airspeed returns to the top of the amberband.

Flight-director guidance can be brought back, and the autopilot engagement inhibit can be removed, before airspeed returns to the top of the amberband by selecting pitch modes

with reversionary speed protection. Using LVL CHG or V/S for flaps up through flaps 10 or LVL CHG for any flap setting will restore flight-director guidance and enable re-engagement of the autopilot while still in the amberband. Selection of TO/GA, when that mode is available, will also bring back the flight-director guidance and remove the autopilot engagement inhibit. For G/S or G/P, only the selection of TO/GA will bring back the flight-director guidance and remove the autopilot engage inhibit prior to reaching the top of the amberband because other mode selections are not allowed.

The Autopilot Disconnect and Flight Director BOV changes do not apply to dual-channel operations or redundant latch due to the short duration of the associated flight phase; the priority given to following the command path; the high level of pilot vigilance during this final portion of the landing phase; and the need to ensure autopilot and flight director availability during low-visibility conditions and windshear events.

6.4 MAX Display System (MDS) Updates for AOA DISAGREE

The 737 MAX MDS software change updates the AOA DISAGREE annunciation logic and addresses Safety Item #5: AOA DISAGREE. The AOA DISAGREE annunciation is displayed on the captain's and first officer's PFD when the left and right AOA values differ by more than 10 degrees for longer than 10 continuous seconds. An optional AOA gauge displays the AOA value on the captain's and first officer's PFD when the option is enabled. The AOA DISAGREE annunciation and AOA gauge are illustrated in Figure 4.



FIGURE 4 737 MAX MDS PFD WITH AOA DISAGREE AND AOA GAUGE

Prior to the change, the 737 MAX MDS software:

- Associated the AOA DISAGREE annunciation with the AOA gauge option, such that the AOA DISAGREE annunciation functioned only when the AOA gauge option was enabled.
- Allowed blanking of the AOA DISAGREE annunciation below 400'.

The 737 MAX MDS software change updates the MDS software to:

- Ensure the AOA DISAGREE annunciation logic is always enabled, regardless of the AOA gauge option.
- Maintains the AOA DISAGREE annunciation below 400 feet radio altitude displayed through landing to avoid the flightcrew missing the alert during a high workload condition.

In addition to the AOA DISAGREE annunciation changes, the 737 MDS software change updates the MDS so the software can detect whether different software part numbers are installed on the display-system computers. The DISPLAYS SOFTWARE CONFIG status message will be displayed if not all the display computers have the same software part number.

6.5 Non Normal Checklists (NNC)

Below is a description of changes to NNCs associated with the MCAS design change that address Safety Item #4: FLIGHTCREW RECOGNITION AND RESPONSE. The FAA will include these NNC changes in the AFM changes required by the RTS AD. The FAA also will provide the changes to operators via the Ops Manual Bulletin prior to return to service for incorporation into operator's Quick Reference Handbook (QRH). The NNCs are changed as follows:

1. SPEED TRIM FAIL

- To improve pilot awareness the condition statement for this NNC is updated to reflect that the STS will be inoperative for the remainder of the flight. Stabilizer speed-trim inputs will not be provided when deviating from a trimmed airspeed. This checklist is included in the AFM.

2. Airspeed Unreliable

- To reduce crew workload, the NNC adds a step allowing the flightcrew to determine a reliable airspeed indication without referring to pitch-and-power reference tables. The procedure for go-arounds allows for increased use of automation provided that the flightcrew has determined pitch and power settings if flight director guidance is lost. A step to select the reliable

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transponder was revised to ensure that erroneous altitude information is not transmitted to Air Traffic Control (ATC).

3. AOA DISAGREE

- The NNC is simplified to direct the flightcrew to the Airspeed Unreliable NNC when there is an indication that the left and right AOA vanes disagree. This checklist is added as a procedure in the AFM.

4. ALT DISAGREE

- The NNC includes an additional step directing the flightcrew to the Airspeed Unreliable NNC if the IAS DISAGREE alert is also shown on the flight instruments. This checklist is included in the AFM.

5. Runaway Stabilizer

- The condition statement for this NNC is modified to include situations when un-commanded stabilizer movement occurs continuously or in a manner not appropriate for flight conditions. The NNC is reformulated to move existing text for controlling pitch attitude with the control column and new text to control airspeed with thrust levers into newly created memory steps, in addition to using main electric trim to reduce control column forces. A note that reducing airspeed eases effort needed for use of manual trim is also added.

6. Stabilizer Trim Inoperative

- This NNC is modified to emphasize information concerning use of manual trim. A note to reduce airspeed for improving use of manual trim was added to align the procedure with the Runaway Stabilizer NNC.

7. STAB OUT OF TRIM

- This NNC is revised to alert flightcrews that the Cross-FCC Trim Monitor has been activated in flight when the STAB OUT OF TRIM alert is illuminated on the ground after landing. An added step directs flightcrews not to take off when the alert is illuminated on the ground. This checklist is included in the AFM.

8. IAS DISAGREE:

- This NNC directs the flightcrew to accomplish the Airspeed Unreliable NNC when the captain's and first officer's airspeed indicators disagree. No changes were made to the NNC and it is now included in the AFM.

6.6 Electrical Wiring Interconnection System (EWIS) Requirements (14 CFR 25.1707)

As part of the FAA's review of these design changes, the agency re-reviewed the entirety of the 737 MAX horizontal stabilizer control system. This review revealed that the physical separation of the horizontal stabilizer trim-arm wiring and the horizontal stabilizer trim-control wiring does not meet the criteria specified in 14 CFR 25.1707. The FAA promulgated this design standard in 2007 and therefore it is part of the certification basis of the 737 MAX but not of previous Boeing Model 737 airplanes. Certain wiring installations must have enough physical separation so that a wiring failure cannot create a hazard. (See 14 CFR 25.1707).

Since design changes must comply with FAA regulations, the FAA requires changes to the wiring installation to meet the required physical separation between the horizontal stabilizer trim-arm wiring and the horizontal stabilizer trim-control wiring. This action brings the airplanes into regulatory compliance. The stabilizer trim-arm wiring has since been rerouted in 12 areas of the airplane's Electrical Equipment bay and Section 48 to prevent a potential simultaneous short circuit between the stabilizer arm and control wiring and another 28VDC wire. The 737 MAX design change will include physical separation of existing wires and/or routing of new wires to ensure compliance with the regulation. (See Figure 5).

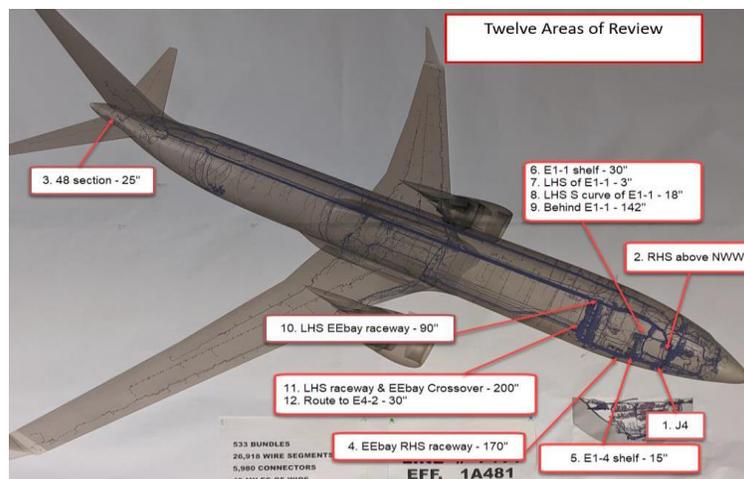


FIGURE 5 737 MAX STABILIZER TRIM MOTOR WIRE SEPARATION

7. Training Enhancements

The 737 MAX Joint Operations Evaluation Board (JOEB) concluded evaluation activities at London Gatwick Airport on September 22, 2020. The JOEB included civil aviation authorities and airline flightcrews from the United States, Canada, Brazil and the European Union. The civil aviation authorities and industry pilots selected for participation

completed all scheduled tasks as planned. The JOEB determined that all design changes applicable to the 737 MAX are operationally suitable. The Board's evaluations also included assessments of Boeing's proposed differences training and return to service training. The joint authorities, through evaluations of multiple crews from a globally diverse pilot group, determined that the proposed training by the applicant was acceptable. The FAA posted the draft 737 Flight Standardization Board (FSB) report for public comment on October 6, 2020. The comment period closed on November 2, 2020 and the FAA considered all comments made adjustments to the FSB report for clarity where needed. The FAA published the final version of the 737 FSB report, revision 17, on November 18, 2020. The final version adds training requirements for the MCAS, Autopilot Flight Director System (AFDS) enhancements, and additional Special Emphasis Training. The FAA added Appendix 7 to delineate 737 MAX ground and flight training necessary to operate the 737 MAX modified with the new FCC software. You can view the final report on [this page](#).

8. Certification Project: Key Compliance Activities

During its evaluation of Boeing's proposed modifications, the FAA retained all compliance findings and approvals associated with the design changes related to MCAS. This unprecedented level of review has taken more than 22 months and included the full-time work of more than 40 engineers, inspectors, pilots and technical support staff. The effort represents more than 60,000 FAA hours of review, certification testing and on-site evaluation of pertinent documents. This includes approximately 50 hours of FAA flight or simulator tests and FAA analysis of more than 4,000 hours of company flight and simulator testing. In addition, the FAA supported multiple concurrent validation activities with four foreign authorities and conducted regular outreach sessions with the applicable CAA community.

8.1 System Change Development and Certification Process

NOTE: Unless noted otherwise and in accordance with FAA rules (see 14 CFR 21.21) and policy (see FAA Order 8110.4c, paragraph 2-6.(j)(2)) Boeing developed all data (also known as substantiating data) and conducted all analysis and tests that are referenced in this report. The FAA oversees the process, reviews select substantiating data and may repeat any or all testing that the applicant conducts.

14 CFR Part 21 addresses changes to Type Certificates (TC) (see 14 CFR Part 21 Subpart D). The FAA approves major changes to type design using the type-certification process described in Chapter 2 of FAA Order 8110.4C, *Type Certification*. A type-design change is developed and assessed for effects to the overall airplane type design per requirements in 14 CFR 21.93 using an FAA-approved process. For major changes, the FAA must establish new findings of compliance for the changed areas.

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During a certification project, the FAA works with the applicant to manage the compliance activities and deliverables. The applicant describes the proposed change to the FAA, and includes functional and design details pertinent to the certification project. The applicant prepares a certification plan using requirements established by that model's certification basis at the time of type certification (or amended type certification for a derivative such as the 737 MAX), as well as a description of how it will show compliance, including any airplane test activities. Once the FAA accepts this plan and either retains or delegates approval of the project, compliance activities can begin. Depending on the complexity of the change, multiple lower-level certification plans may be developed for each area of change (e.g., flight controls, stabilizer system) and individual items within each plan may be subject to FAA involvement.

Compliance activities depend on the means of compliance that the FAA accepted in the certification plan. Some examples include:

- Review of design against design requirements listed in the regulations
- Calculation and analysis against performance requirements
- Safety assessment using safety analysis techniques and documentation
- Testing of components or systems in a lab against performance requirements
- Simulator testing of functionality and interfaces in lieu of testing on an actual airplane, and
- Airplane testing of specific conditions on the ground or in flight.

Simulator and airplane test activities require creating a test plan providing details and rationale for the test conditions selected. The applicant submits the plan to the FAA for acceptance, in accordance with FAA Order 8100.4C. Test-related activities require the FAA (or designee) to conform the test setup and test article to verify that the test will generate data clearly supporting compliance and demonstrate how the change will comply. When testing is complete, the results — as well as applicable observations of the conduct of the test — are documented in an approved certification test report.

Compliance activities serve as a demonstration of compliance to the FAA as well as a means to collect substantiation data for analysis and documentation to support a finding of compliance. This documentation becomes a certification deliverable. If it is required for project certification, the applicant submits it to the FAA or its designee for review and acceptance as justification that the change meets the applicable regulatory requirements.

When the applicant submits all compliance data deliverables and the FAA or its designee approve them, the project is closed and the change is certified. Then, the certification is approved as airworthy when installed on an airplane and that airplane receives its Certificate of Airworthiness or, for aircraft in service, an approval for return to service in the aircraft logbook as applicable under the appropriate operational rules (e.g., 14 CFR parts 121 or 135) or maintenance rules (e.g., 14 CFR parts 43 or 145).

8.2 Certification Requirements

Certification requirements are the regulations applicable to the systems and functions that are changed, as well as the airplane-level compliance effects of those changes. The amendment levels of the regulations are determined at the time of Amended Type Certification, as captured in the Certification Basis in the FAA Type Certification Data Sheet (TCDS) A16WE. The MCAS was designed and certified for the 737 MAX to enhance the pitch stability of the airplane. As such, the design change is neither substantial (the change in design is not so extensive to require a complete investigation of compliance) nor significant (there was no change to the general configuration or the assumptions used for certification) from a product-level-change point of view. Rather, and most importantly, MCAS enhances the earlier design philosophy to be more robust. Therefore Boeing was required to demonstrate compliance with the existing 737 MAX Certification Basis. The regulations below apply to the changes listed in Section 6. A description of these regulations can be found [online](#) in the FAA Regulatory and Guidance Library.

14 CFR Regulation	Amendment	14 CFR Regulation	Amendment
21.21(b)(2)	[21-92]	25.1317(a)	[25-122]
21.35(a)(4)	[21-95]	25.1322(a)(1)(i)	[25-131]
25.201	[25-108]	25.1322(a)(1)(ii)	[25-131]
25.203	[25-84]	25.1322(a)(3)	[25-131]
25.601	[25-0]	25.1322(c)(1)	[25-131]
25.671(c)(1)	[25-23]	25.1322(f)	[25-131]
25.671(c)(2)	[25-23]	25.1329(d)	[25-119]
25.672	[25-23]	25.1353(a)	[25-123]
25.1301(a)(1)	[25-123]	25.1431(c)	[25-113]
25.1301(a)(2)	[25-123]	25.1523	[25-3]
25.1301(a)(3)	[25-123]	25.1535	[25-120]
25.1301(a)(4)	[25-123]	25.1581	[25-72]
25.1302	[25-137]	25.1583	[25-130]
25.1309	[25-123]	25.1585	[25-105]
25.1309(a)	[25-123]	25ADRC-25.1322(b)(2)	[25-NA]
25.1309(b)	[25-123]	25ADRC-25.1322(c)(3)	[25-NA]

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14 CFR Regulation	Amendment	14 CFR Regulation	Amendment
25.1309(c)	[25-123]	25App-K25.1.1	[25-120]
25.1309(d)	[25-123]	25App-K25.1.2	[25-120]
25.1316(a)	[25-80]		

In addition to FAA regulations, two Additional Design Requirements and Conditions (ADRCs) apply to this change. These two ADRCs are found in the TCDS A16WE.

8.3 Means of Compliance

8.3.1 Design Review

The design changes to the Speed Trim System with updated MCAS function, autopilot disconnect at stick shaker, and the integrated Flight Deck, are not novel. The design changes upgrade the related systems and procedures, enhance the design, protect against the causal factors noted in the accidents, and add additional safety enhancements.

The FAA’s review and approval of the Service Information to install the updated FCC software in retrofit on the 737 MAX airplanes is based upon the agency's evaluation of Boeing’s design and the applicability of the parts and data. This review ensures compliance with the certification basis upon approval of the deliverables identified in the certification plan. This section is not all-inclusive but does highlight areas the FAA focused on (see note in section 8.1). However, Boeing addressed all compliance requirements in the certification basis (see section 8.2)

8.3.2 Calculations and Analysis

Boeing met all development assurance (DA) requirements in accordance with the Boeing Commercial Airplanes DA Plan for Type Design Changes. The FAA approved this document.

Boeing conducted an analysis of the updated FCC software using updated 737 MAX engineering flight-simulation data. The analysis, which the FAA evaluated, assessed the installation, functional design, operation and performance requirements to show compliance with the FAA regulations listed in section 8.2 of this document.

The analysis included a review of supporting DA artifacts that capture the system’s DA processes including requirements development, validation, verification, configuration management, process assurance, and safety analysis per FAA policy requiring that the

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objectives of SAE Aerospace Recommended Practice (ARP) 4754A and EUROCAE ED-79 (two widely-used means of compliance) be satisfied for the FCC software update.

Data from simulator evaluations demonstrating performance of the MCAS activation/resynchronization logic, AOA MVS and split vane monitor, and MCAS maximum command limit changes, in the presence of an erroneous elevated AOA event, were analyzed to show compliance to 14 CFR 25.601.

Similarity analysis was used to show that the findings from the 737-7 flight tests are applicable to the 737 MAX, and that the 737-8 simulator test results for the updated FCC software are applicable to the 737-9.

The analysis incorporated a representative flight-controls update to show the effects of the control-law improvements on the handling characteristics of the airplane. The extension of the MCAS command schedule to lower Mach numbers has an improved column force gradient during approach to stall than what is currently certified. The lower Mach numbers in a stall can only be reached at very light weight and low altitudes, which cannot be safely flight tested.

The control-law improvement is limited to a very specific area of the control law for specific conditions as described above and in the System Description section of the certification plan. Hence, the analysis showed the change was compliant.

For compliance with 14 CFR 25.1302, Boeing assessed the changes to the Speed Trim System with updated MCAS function, autopilot disconnect at stick shaker logic, and the integrated Flight Deck at the level of change for the system. The analysis was supported through assessment of the design in an engineering simulator per guidance in Advisory Circular (AC) 25.1302-1, *Installed Systems and Equipment for Use by the Flightcrew*. Multiple focused evaluations with two-subject flightcrews of Boeing pilots and airline pilots took place in an engineering simulator to validate the analysis of the design to the requirements.

An analysis of the update to the SPEED TRIM FAIL caution crew alert and STAB OUT OF TRIM caution crew alert showed compliance with 14 CFR 25.1322 and Compliance Standard (CS) 25.1322. An analysis of the change to the MCAS function showed that the crew workload is within capabilities of a two-pilot flightcrew. Observations of engineering simulator evaluations, completed as part of the 14 CFR 25.1302 evaluations, supported the analysis. Note: The crew workload associated with the MCAS function is assessed as being the same or less than the 737-8/-9 baseline.

For compliance with 14 CFR Part 25 Appendix K, K25.1.1 and K25.1.2, an analysis demonstrated that the maximum flight time and longest diversion times are considered, in support of a 180-minute ETOPS (Extended Operations) Type Design Approval, plus a 15-minute contingency. The analysis, which was conducted in accordance with an FAA Issue Paper, also verified that crew workload, operational implications, and the physiological needs of crew and passengers are considered with failure effects for the longest diversion time. .

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Stabilizer Trim Wheel Forces comply with 14 CFR 25.143 by analysis per EASA CRI B-17 because existing guidance does not cover stabilizer-trim-wheel forces. Simulator predictions, validated by flight test, were used to calculate the required stabilizer trim wheel forces and a mockup of the stab trim wheels was used to measure the force capability of appropriate pilots.

An analysis of the pilot capability of applying force to the manual stabilizer trim wheel for defined scenarios where pilots may potentially be required to use manual trim to ensure safe controllability and maneuverability during all phases of flight will be completed.

An analysis of the performance of Stall Identification Devices against requirements listed in 14 CFR 25.671(c)(1), 25.672, and 1309(b) was conducted. Although not directly affected by this change, this review was included to address additional questions raised in part by the FAA's review of the MCAS design change.

A review of the applicable compliance data ensured that the FCC operates within acceptable electromagnetic effects limits for installation on the airplane and that the FCC does not constitute a safety hazard within the installation environment during foreseeable operating conditions. Additionally, a similarity analysis of the baseline tested FCC and the modified FCC software showed the form, fit and function in the design is acceptable and the baseline configuration has been tested in the required Electro Magnetic Compatibility conditions.

An analysis of the update to the AOA DISAGREE caution crew alert in the flight deck showed compliance with 14 CFR 25.1322 and CS 25.1322 in accordance with FAA policy for Flightcrew Alerting in AC 25.1322-1.

8.3.3 Safety Assessment

Boeing completed individual safety assessments on the Enhanced Digital Flight Control System (EDFCS) and Stabilizer to show that those systems' designs meet the reliability and integrity safety requirements for the 737 MAX. Assessments include Failure Mode Effects Analysis, Functional Hazard Assessments and Fault Tree Analysis. In addition to the individual safety assessments, Boeing developed an integrated System Safety Analysis (SSA) for the Speed Trim System with an emphasis on MCAS, including upstream and downstream interfaces. The integrated SSA was developed to aid in the showing and finding of compliance based on the integration of the systems noted above and their relation to each other. This decision meant the FAA had to review and cross reference systems without relying on Boeing's computer-aided design tools. The integrated SSA enabled the FAA to trace systems and make safety determinations using a single document that integrated the analysis, rather than simultaneous tracing through multiple documents.

Reliance on Pilot Mitigations

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The FAA's review of the integrated SSA included an evaluation of Boeing's STS design changes to determine if any STS failure modes rely on pilot reaction times to maintain safe operation of the aircraft. The FAA's review of the integrated SSA and validated through extensive failure modes testing in simulators, the FAA concluded that no STS failure modes rely on exceptional piloting skills, and do not rely on immediate pilot actions. (See 8.3.2, 8.5, 8.6, and 9.1 of this report)

Single Point Failures

The FAA's review of the integrated SSA included an evaluation of Boeing's STS design changes. The FAA's review determined that there is no evidence that STS functionality is vulnerable to any other single-point failures, which can result in a catastrophic outcome.

8.4 Software

The software life-cycle data was reviewed against RTCA DO-178B and DO-178B errata in DO-248B objectives and D6-85001 Revision G guidance. RTCA DO-178B and DO-178B errata in DO-248B are FAA-approved means of compliance used to demonstrate software development, quality and functionality in accordance with AC 20-115D, Airborne Software DA Using EUROCAE ED-12() and RTCA DO-178().

The review directly verified the Software Configuration Indices SCI to demonstrate they contain the correct information for creating the software and for defining the design baseline. The Software D6-85001 Chapters, FAA IPs, EASA Certification Review Items (CRI), and FAA Transport Airplane Issues List (TAIL) items which apply to this certification project are:

- 737-8/-9/-7 IP SW-1a, "Software Aspects of Airborne Systems and Equipment Certification."
- D6-85001 revision G chapter 13, "Properly Overseeing Suppliers", will be used by Boeing to address IP SW-2 "Oversight of Suppliers of digital Airborne System and Equipment containing Software."
- D6-85001 revision G chapter 14, Software Problem Reporting, will be used to address IP SW-3 "Management of Software Problem Reports". This also addresses TAIL item "Management of Open Problem Reports."
- TAIL item "Software Maturity Prior to Flight," is addressed with D6-85001 revision G chapter 18 "Software Requirements for Type Inspection Authorization".

8.5 Flight Test

More than 4,000 hours of flight testing supported the design changes associated with the updated FCC software and updated MDS software. These tests included certification testing to validate the SSA and the determination of failure-effects hazard classification by FAA Flight Test Pilots in a conformed engineering simulator. Additionally, the FAA flew

aircraft certification flight tests under Type Inspection Authorization to find compliance with 14 CFR 25.1301, regarding function and installation, as well as 14 CFR 25.1309, to confirm continued safe flight and landing following a complete failure of the Speed Trim System/MCAS functions.

Additionally, a matrix of stall-identification and stall-characteristics testing confirmed that basic airplane stall characteristics comply with those regulations, both with and without STS/MCAS operation. The FAA also flew engineering flight tests to validate manual-trim wheel forces and confirm that even for the most critical failures identified within the SSA, manual-trim capability was adequate through all phases of flight — and associated configurations changes — to accomplish continued safe flight and landing. (See 8.3.2, 8.6, and 9.1 of this report for further details.)

8.6 Flightcrew Operations (14 CFR 25.1302 and 25.1523) Compliance Reports

Boeing testing included extensive human-factors and crew-workload testing. The intent of this testing was to observe the use of the integrated flight-deck design by line pilots during operationally realistic scenarios. Section 25.1302, Installed systems and equipment for use by the flightcrew, focuses on minimizing the occurrence of design-related errors, and enabling the crew to detect and manage errors if they do occur. Section 25.1523, Minimum flightcrew, focuses on crew requirements for safe operation considering crew workload and controls. The FAA and Boeing used the evaluations to support:

- Validation of pilot-action assumptions behind the updated FCC software design and return to service for the 737 MAX,
- Identifying any potential crew errors related to interaction with the STS including MCAS function that had not been determined through analysis,
- Assessing that the design is error tolerant,
- Assessing that the design changes to the STS are clear and unambiguous, and
- Assessing that workload is acceptable for failure conditions where there may be erroneous or inhibited STS/MCAS behavior.

The tests used four airline crews (three domestic crews and one international crew), each consisting of a captain and first officer. Flightcrews were from airlines operating the 737 MAX, based on employment with a U.S. or foreign air carrier, licensing level, varying experience level and crew position as a non-managerial or check pilot. Crew selection was intended to represent the cross-section of pilots expected to operate the 737 MAX in air carrier operation. FAA flight test, Human Factors (HF) specialists, and Aircraft Evaluation Division (AED) operations personnel were directly involved with the planning and execution of the evaluations. In addition, both EASA and TCCA specialists participated as observers in the evaluation.

The objective for these evaluations was to observe line pilot use of the flight-deck design related to MCAS and FCC software during operationally realistic scenarios. Evaluations validated Boeing's analysis, which examined usability of the design by flightcrews, design tolerance to crew errors, and crew workload. These evaluations focused on the certification and design changes in the FCC software, as well as how these updates integrate into the 737 MAX flight-deck design. These evaluations were scenario based and designed to be executed naturalistically without crews being directed to perform specific actions. Boeing selected, and the FAA accepted, test-condition scenarios based on the difficulty for crews to detect, respond to and manage various failure modes.

The Failure Modes and Effects Analysis and Single and Multiple Failure analysis were used in developing the test scenarios. The scenarios included: Small AOA vane bias (less than 5.5 deg. threshold); Erroneous Mach on go-around; Large AOA vane bias (40 deg.); Sheared AOA vane on takeoff (just beyond V_R); Pitch attitude error; FCC inserts erroneous trim command and issues erroneous monitor activation with Autopilot engaged; and FCC inserts erroneous trim command and issues erroneous monitor activation during manual flight. A minimum of four of the seven scenarios were presented to each crew due to session-length constraints as well as minimizing crew exposure to multiple conditions with similar effects and responses.

8.7 Flightcrew Alerting (14 CFR 25.1322) Evaluation

The FAA instructed Boeing to assess potential failures of the flight control system, as well as potential flightcrew responses to the failures. The 737 MAX RTS activities include a top-down, holistic approach to crew-alerting requirements. The updates associated with the FCC MCAS software design changes, combined with training and procedure updates, address the known 737 MAX safety issues. The FAA evaluated flightcrew alerting from a system perspective including consideration for the system design, updated flightcrew procedures and the new training program.

The 737 MAX Crew Alerting System is based on the Crew Alerting System of the 737 NG which has shown, through extensive fleet service history (more than 170 million flight hours) to be safe and effective. The 737 MAX design changed and added select alerts compared to the 737 NG to comply with the latest regulations or provide crew awareness of unique non-normal operations. However, these were not extensive changes to the Crew Alerting System. The proposed MCAS design changes do not change the 737 MAX Crew Alerting System as a whole and maintain commonality with the flight-deck-alerting design philosophy and training of the 737 NG.

Flightcrew alerts on the 737 are presented in the flight deck by indicator lights, displays, voice aural, tone aural and stick shaker. Each crew alert is tied to a checklist procedure or a flightcrew maneuver captured in the QRH. Indications not tied to a checklist or maneuver in the QRH are not considered flightcrew alerts, and include indications such as failure flags on instruments, information lights on control panels, and normal voice aural callouts and aural tones. Visual warning and caution alerts presented in the flightcrew's

forward field of view are readily and easily detectable and are inherently attention-getting during a normal panel scan.

Most visual warning alerts are presented in the flightcrew's primary field of view in the color red, or have a master visual attention-getting cue in the primary field of view or an aural attention-getting cue to assure immediate crew awareness of the condition. Visual caution alerts presented in the flightcrew's forward field of view are colored amber and, where needed, have attention-getting attributes, either visual or aural, to assure the flightcrew is adequately made aware of the condition indicated by the caution. The master caution function on the 737 MAX serves the same purpose as on all previous 737 models, and helps reduce crew workload by removing the need for scanning the overhead panel and aisle stand for the presence of new caution lights. The Master Caution and associated 6-pack (six-light annunciator panel) provide alerting in the flightcrew's forward field of view that are readily and easily detectable. Two master caution lights and two 6-packs are located on the pilot's glare shield panel, which is within the flightcrew's forward field of view. The 6-packs identify 12 separate system panels or locations where a particular caution alert indicator light can be readily located by the flightcrew.

The current system design includes assuring all displays are viewable by both pilots for all lighting conditions. The revised AFM, including Non Normal Checklists procedures, clarifies recall items (minimum immediate actions). Specific changes to the NNCs will streamline execution by the flightcrew when handling system failures, and in conjunction with significant improvements in the MCAS design, reduce flightcrew workload in handling multiple alerts.

8.8 Evaluation of the Airspeed Unreliable Non Normal Checklist

Analysis of the JT610 and ET302 accidents indicate excessive crew workload is one of several causal factors in both accidents. Due to a single failure of the AOA sensor, the crews were faced with a controllability problem exacerbated by multiple erroneous indications and cockpit warnings that led to excessive crew workload. As part of the certification of design changes to the 737MAX, the FAA carefully reviewed all possible failure conditions and the associated flight-deck effects, which contribute to crew workload and possible mitigations for those contributors. The FAA determined that the MCAS original functional design — notably, a design feature allowing multiple, airplane nose down inputs from a single, erroneous high AOA event — was the largest contributor to crew workload challenges. The Boeing design changes (outlined in section 6) eliminate the controllability issues evident in these two accidents. The controllability aspect of these failures was, by far, the largest contributor to crew workload and the only flight-deck effect that prevented continued safe flight and landing. With these changes incorporated, this same failure now results in a workload assessed to be manageable by a properly trained crew without the need for exceptional skill, alertness or strength, and was found to comply with U.S. regulations that govern transport aircraft design safety during aircraft system failures. Additionally, the enhanced training program outlined in section 7, when

implemented, will substantially increase flightcrews' ability to manage the remaining workload.

The design-change improvements to flight-control-system behavior and subsequent controllability during failures notwithstanding, the FAA and Boeing considered other possible methods to improve safety through reduced flight-crew workload. The FAA and civil aviation authorities from other countries agreed that a means to silence nuisance stick-shaker events, (from erroneous high AOA sensor data), while not required for compliance, would reduce flight deck noise and potentially reduce crew distraction and workload. The FAA concluded that disabling nuisance stick-shaker events is desirable provided the method complies with appropriate FAA regulations and does not introduce new safety concerns. FAA and Boeing informally discussed several means to silence the single erroneous stick shaker.

As other foreign civil aviation authorities suggested, Boeing and the FAA discussed adding a step or note in the Airspeed Unreliable NNC that provides the pilot an option to disable the stick shaker by pulling the appropriate stick shaker system circuit breaker. As with other aspects of the Boeing-proposed design change to MCAS, the FAA tasked the TAB with studying the proposed alternative NNC (with circuit breaker pull) and providing an independent opinion of its merits. The TAB agreed that minimizing the effects of false and nuisance alerts is desirable and supported by FAA guidance (AC 25.1322-1) that states, "*a flightcrew alerting system must be designed to provide a means to suppress an attention-getting component of an alert caused by a failure of the alerting system that interferes with the flightcrew's ability to safely operate the airplane.*"

The TAB therefore set out to answer a fundamental question: Does this [737 MAX] false stick-shaker activation interfere with the flightcrew's ability to safely operate the airplane? The FAA essentially answered this fundamental question as "no" by concluding that the effect on the airplane and crew of the failure is "Major" in the context of § 25.1309 System Safety Analysis and associated Functional Hazard Assessment. That is, safety margins are reduced, and crew workload is increased, however the failure does not excessively impair the crew's ability to perform their duties. In accordance with FAA regulations and policy, and considering the probability and testing of failure effects if the effect is "Major", the airplane can still be operated safely, so using the FAA determination a false stick-shaker activation does not need to be suppressed. If the effect is "hazardous," (which is more severe than "major") the false stick-shaker activation, owing to the probability that it could occur, would need to be suppressed. The FAA's evidence for its "major" determination are (a) the flight simulator evaluations by FAA and Boeing pilots during § 25.1309 testing, (see sections 8.3 and 8.5); (b) airline flightcrews used in § 25.1302/1532 tests (see section 8.6); and (c) service history of similar failure events on the B737NG fleet. By contrast, the TAB was unable to find objective evidence for a "hazardous" determination with regard to the test conditions, pilot skill levels, and reliability of the results.

The TAB provided a commentary on certification considerations that suggests, as a routine matter for any certification project, the proposed CB pull NNCs should be supported by the

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necessary certification data. Ergonomic data and simulator test data need to be evaluated for compliance with all applicable regulations.

In consideration of the TAB's opinion, the FAA and Boeing considered an alternative Airspeed Unreliable NNC that includes the use of a circuit breaker to disable an erroneous stick shaker on the 737 MAX aircraft. The FAA evaluated this alternative NNC in addition to the same NNC (without a circuit breaker pull) used in our certification testing of 737 MAX post-accident design changes. The FAA evaluation used multiple crews that included three certification-flight test pilots and three operations evaluation pilots who were all 737 type rated with a broad range of operational experience. The pilots' stature ranged from 5 feet 6 inches tall to 6 feet 6 inches tall, which reasonably represents FAA regulatory requirements (§ 25.777(c)). To supplement the flightcrews, FAA participants included a flight test engineer and two human factors specialists. Multiple tests were conducted using a 737 MAX engineering simulator and a 737 MAX full flight simulator. In all, FAA crews performed 42 test cases and accumulated 15.5 hours of simulated flight time. The testing included use of a variety of circuit breaker collars that can aid in identification, as well as ease of pulling the correct circuit breaker.

The evaluation of cockpit procedures relies on engineering judgment in evaluating compliance with several FAA regulations including 14 CFR 25.771 Pilot compartment; § 25.777 Cockpit controls; § 25.1301 Function and installation; § 25.1302 Installed systems and equipment for use by the flightcrew; § 25.1309 Equipment, systems, and installations; § 25.1523 Minimum flightcrew; 25.1357 Circuit Protective Devices and 25.1585 Operating Procedures.

The FAA's test results found that all participants agreed that the alternative NNC (with CB pull) may not be in alignment with the intent of 14 CFR 25.777(a) and (c). Section 25.777(a) states that each cockpit control must be located to provide convenient operation and to prevent confusion and inadvertent operation. Section 25.777(c) states that the controls must be located and arranged, with respect to the pilots' seats, so that there is full and unrestricted movement of each control without interference from the cockpit structure or the clothing of the minimum flightcrew (established under § 25.1523) when any member of this flightcrew, from 5'2" to 6'3" in height, is seated with the seat belt and shoulder harness (if provided) fastened.

Although the crews were eventually able to reach and successfully pull the appropriate circuit breaker, they were not able to do so while seated with their seat belt and shoulder harness properly fastened, or without excessively deviating their attention from their primary duties of pilot flying or pilot monitoring. The need to partially unbuckle a shoulder harnesses or seatbelt, as shown during FAA testing, introduces a new safety hazard during erroneous high-AOA events. One evaluator had to exit his seat and required an extended period of time to locate the circuit breaker. The FAA further found that the participants questioned the system meeting several other regulations (§§ 25.771, 25.1301, 25.1309, 25.1585). The FAA considered potential cases where a pilot pulled a nearby but incorrect circuit breaker. In one case, pulling the wrong circuit breaker indeed silenced the erroneous stick shaker but introduced other flight-deck effects that produced

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new and undetected hazards. The flight-deck effects in this case were difficult to immediately assess during testing. These additional hazards, combined with the poor accessibility of these specific circuit breakers, also introduced safety and compliance concerns to other FAA human factors regulations such as §§ 25.1302 and 25.1523. The FAA concluded that due to its determination that an erroneous high-AOA event poses a "major" rather than a more severe threat to aircraft operations, the potential safety risk introduced by the circuit breaker pull in the NNC outweighs the safety benefit of silencing a nuisance stick shaker in the 737 MAX.

The international nature of aviation brings unique design challenges for manufactures in that each country must evaluate aircraft designs for use by their own operators and in consideration of their own operating environments. At the same time, the FAA and other CAAs work hard to accommodate the needs of each country that operates an aircraft for which they have State of Design responsibility. The FAA, as the State of Design for U.S. products, must consider the design in the context of U.S. operations as well as worldwide use of the products. Such is not the case for the validating authorities, which are able to focus solely on the design within the context of their operations and training infrastructure. Many countries choose to accept FAA design approvals without change, while others may have unique requirements based on differences in their regulatory structure, operations and/or training. In most cases, minor adjustments to the FAA-approved design or adjustments to how the aircraft is operated are needed to account for the unique knowledge, skills and cultural norms of each country or region. For these reasons, it is common for an aircraft manufactured in the U.S., Brazil, Canada, or Europe, for example, to have variations from country to country in aircraft operating limitations or procedures.

9. Operational Suitability Evaluation, Including Procedures and Training

9.1 Flight Standardization Board

The FAA's Aircraft Evaluation Division (AED) is responsible for working with aircraft manufacturers and modifiers during the development and FAA certification of new and modified aircraft to determine: 1) the pilot type rating; 2) flightcrew member training, checking, and currency requirements; and 3) operational suitability. To help evaluate some of these functions for the 737 MAX aircraft, the AED formed a FSB. The AED formed the FSB consistent with FAA AC 120-53B, Guidance for Conducting and Use of Flight Standardization Board Evaluations, change 1. The evaluation results for the 737-8 MAX initial evaluation is contained in Revision 14 of the FSB Report, dated July 5, 2017. The FAA evaluated the 737-9 MAX and added it to the 737 FSB Report contained in revision 15, dated January 2, 2018. Revision 16 of the FSB Report, dated October 17, 2018 added the Boeing Business Jet 737-8 MAX.

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Following revision 16 of the 737 FSB Report in March 2019, the FSB evaluated an early modified version of the FCC software to determine training and checking requirements relating to MCAS. The FSB conducted the evaluations at the Boeing Flight Training Center using the 737-800 and the 737 MAX series full flight simulators (FFS). The FSB first conducted a T2 test followed by a T1 test. It conducted both tests in accordance with FAA AC 120-53B. The T2 test evaluated pilot handling characteristics between the 737 NG and the 737 MAX series aircraft during maneuvers when MCAS was active. The T1 test evaluated functional equivalence between original and the earlier modified version software loads in the 737 MAX FFS during normal MCAS operation and speed-trim-failed (MCAS) conditions.

The FSB evaluated the 737 MAX MCAS operation in both normal and non-normal (speed-trim-failed) operation of the system including the following test scenarios:

- MCAS Operational: Approach to stall in the clean configuration and recovery procedures conducted at low, mid and high altitudes.
- MCAS Failed (includes Speed Trim Failed): Approach to stall in the clean configuration and recovery procedures conducted at low, mid and high altitudes.
- MCAS Operational: Extended Envelope to include upset recovery at high bank angles nose-high and nose-low scenarios as required by 14 CFR 121.423 using AC 120-111, Upset Prevention and Recovery Training, guidance. Upsets were performed at low, mid and high altitudes.
- MCAS Failed (includes Speed Trim Failed): Extended envelope to include upset recovery at high bank angles nose-high and nose-low scenarios as required by 14 CFR 121.423, using AC 120-111 guidance. Upsets were performed at low, mid and high altitudes.
- MCAS Operational: Windshear escape maneuver and Ground Proximity Warning System (GPWS) escape maneuver in the clean configuration.
- MCAS failed (includes Speed Trim Failed): Windshear escape maneuver & GPWS escape maneuver in the clean configuration.
- MCAS Operational: Pitch stability evaluation with flaps up at minimum maneuver speed and high maneuvering loads.
- MCAS Failed (includes Speed Trim Failed): Pitch stability evaluation with flaps up at minimum maneuver speed and high maneuvering loads.

Following these evaluations, the FSB determined that no pilot handling differences exist between the 737 NG series and the 737 MAX series during normal operation of MCAS, as well as when the Speed Trim System (MCAS) is failed. The FSB determined that flight training is not required for the earlier modified version of the FCC software. However, it determined ground training is required for initial, transition and upgrade training. Furthermore, recurrent ground training and checking is necessary to ensure pilot knowledge and retention is achieved relating to MCAS system description, functionality,

associated failure conditions and flightcrew alerting. This initial FSB training and checking determination was a provisional determination based on no design changes to the tested version of the FCC Software.

The 737 MAX FCC software subsequently required multiple modifications during the certification process. The final updated FCC software required the FSB to re-evaluate for training and checking requirements. The FAA completed an operational evaluation of the proposed pilot training as a result of the aircraft design changes. The FAA conducted the operational evaluation jointly with Brazil's Agência Nacional de Aviação Civil (ANAC), Transport Canada Civil Aviation (TCCA) and the European Union Aviation Safety Agency (EASA), as described in the next section.

9.2 Flight Standardization Board and Joint Operations Evaluation Board

In September 2020, the FAA completed an operational evaluation of Boeing's proposed pilot training as a result of the aircraft design changes. The FAA conducted the operational evaluation jointly with ANAC, TCCA and EASA. The FAA and the other JOEB CAAs concluded that pilots serving in the Boeing 737 MAX need to complete special training on the Boeing 737 MAX, including ground and simulator flight training. The FAA documented this special training in the Flight Standardization Board Report The Boeing Company 737, Revision 17, dated November 16, 2020.

The report states the ground training must include, but is not limited to, the following elements: MCAS function description and conditions for operation; automatic autopilot disengagement; temporary flight-director removal (bias out of view) manual stabilizer trim operation and trimming techniques; effects of airspeed and aerodynamic loads on manual stabilizer trim operation; and recognition of flight-deck effects of an unreliable airspeed condition (e.g., AOA disagree or failed). The FSB report also states that the ground training may be completed using computer-based training.

As further described in Appendix 7 of the FSB report, the simulator training must include, but is not limited to, the following events: MCAS activation during an impending stall (or full stall) and recovery; a runaway stabilizer condition that requires the pilot to use manual stabilizer trim; operation of each manual trim technique as defined by Boeing (which includes two-pilot intervention); and erroneous high AOA on takeoff that leads to an unreliable airspeed condition with special emphasis on the flight director biasing out of view.

You can view the final report on [this page](#).

10. Evaluation of new maintenance requirements

10.1 Software Upload Considerations

The FAA Aircraft Evaluation Division validated the updated FCC software upload and post-software installation checks. It also validated AMM 22-11-00-740-815 for the new Maintenance Review Board Report (MRBR) task for the Operational check Built-in-test Equipment (BITE) the Arm Signal from FCC to STM. AMM task 22-11-00-740-815 (Digital Flight Control System (DFCS) FCS Speed Trim/Stab Trim Discrete BITE Test) was initially generated as the procedure for the MRBR, which was conducted in accordance with the guidance outlined in AC 121-22C, Maintenance Review Boards, Maintenance Type Boards, and OEM/TCH Recommended Maintenance Procedures. The task also satisfies the Certification Maintenance Requirement (CMR).

10.2 Maintenance Review Board Activity

Boeing's certification plan addressed certification of the final updated version of the EDFCS FCC software for installation on the 737 MAX model airplanes. The certification plan included a CMR included in the Maintenance Planning Document (MPD) section 9. The new CMR addressed Stabilizer Trim Motor Wiring inspections.

The MRBR outlines the minimum scheduled tasking/interval requirements to be used in developing an airworthiness maintenance/inspection program for the airframe, engines, systems and components of the 737-8 and -9 model aircraft. MRBR section 2, Systems and Powerplant tasks were developed from Maintenance Significant Items (MSI) through the MSG-3 process.

Due to FCC software changes (Ref. Boeing Certification Plan), a working group comprised of maintenance and engineering representatives from Boeing, several airlines, the FAA and TCCA reviewed changes to MSI 22-11 Autoflight/Digital Flight Control System. The revised MSG-3 analysis in MSI 22-11 resulted in a new MRBR maintenance task 22-011-00, Operational (BITE) check of the MCAS discrete with a 6000FH inspection interval. The working group also reviewed MSI 27-40 Horizontal Stabilizer and MSI 34-20 Air Data Inertial Reference System and determined no new maintenance tasks were required for these MSIs. The new MCAS task 22-011-00 was approved for inclusion in the 737-8/9 MRBR via a temporary revision by the 737MAX Industry Steering Committee (included the FAA and TCCA).

10.3 Instructions for Continued Airworthiness (ICA) and Maintenance Procedures

The following ICA documents will be updated as appropriate based upon the FAA's review of Boeing's system changes.

10.3.1 Maintenance Planning Document

Changes to the MPD included as part of the system changes are Item Number MPD-22-020-00, generated to add CMR reference 22-CMR-01 that planned to operationally check the Arm Signal from the FCC to STM.

Additionally, MPD Item Number 22-011-00 was generated to add MRBR reference for a proposed inspection out of MSI 22-11. The MRBR 22-011-00 Inspection consists of an operational check (BITE Check) of the MCAS discrete to verify the integrity at 6000 Flight Hours.

The AMM task 22-11-00-740-815 (DFCS Speed Trim/Stab Trim Discrete BITE Test) was initially generated as the procedure for the MRBR requirement. It also satisfies the CMR requirement.

10.3.2 Airplane Maintenance Manual Updates

The AMM had two tasks updated for both Chapter Airline Transport Association (ATA) 22 – Autoflight and Chapter 31 – Displays: Additionally, four system description sections (SDS) have been updated.

- ATA 22-11-00 DFCS AMM Update:
 - 22-11-00-740-815 DFCS Speed Trim/Stab Trim Discret BITE Test: Test for both uncommanded on for the stab trim motor (22-CMR-01) and MCAS and stab trim discret test (Service Bulletin 737-22A1342, TC 6000 hr. inspection).
- ATA 22-11-00 Digital Flight Control System SDS Updates:
 - 22-11-00-025 Speed and Stab Trim Analog Interface: Added more detailed description of MCAS for the column switching module
 - 22-11-00-070 Speed/Autopilot Trim Block Diagram: Added more functional description of MCAS for the STS
 - 22-11-00-071 Speed and Stabilizer Trim Commands: Post SB 737-22A1342 - Mach speed change (from between 0.2 to 0.84; to 0.15 to 0.84)
 - 22-11-00-074 Speed and Stabilizer Trim Warnings: Added more detailed description of MCAS and Speed Trim
- ATA 27-09-00 Flight Controls Multiple Use Systems/Units SDS Update:
 - 27-09-00-003 Flight Controls Multiple Use Systems/Units Panel: Added the system function for the speed trim fail light.
- ATA 27-31-00 Elevator and Tab Control System SDS Update:
 - 27-31-00-017 Elevator and Tab Control System – Elevator Neutral Shift: Added the data for FCC neutral shift function

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- ATA 31-65-02 Display Processing Computer (DPC) AMM Updates:
 - 31-65-02-470-801 DPC – Software Installation: Added the data for DPC Software PN comparison with MAINT light indication
 - 31-65-02-750-801 DPC – Configuration Check: Added data to check the DPC Software Part Numbers
- ATA 34-21-00 Air Data Inertial Reference System (ADIRS) SDS Update:
 - 34-21-00-024 ADIRS - AOA Sensor: Added the data for the AOA Cross Compare and AOA indication.

10.3.3 Fault Isolation Updates

The updated FCC software uses existing maintenance messages to trigger the Speed Trim Fail and Stab Out of Trim warning light for internal faults to the FCC. The message will latch if the detected MCAS troubleshooting differs from the FCC's command. The maintenance messages below trigger an Interactive Fault Isolation Manual (IFIM) task for troubleshooting:

- 22-11303: DFCS - FCC INTERNAL FAULT: FCC-A internal failure: The IFIM task runs tests to determine if FCC A needs to be replaced.
- 22-11317: DFCS - FCC INTERNAL FAULT: FCC-B internal failure: The IFIM task runs tests to determine if FCC B needs to be replaced.

The new overall process for troubleshooting the FCC Cross-Compare maintenance messages on the ground is to:

- Access the maintenance messages via DFCS BITE on the Cockpit Display Unit (CDU)
- Both maintenance messages direct the usage of the CDU, and
- If maintenance message is not cleared after BITE test, the corrective action is to replace corresponding FCC.

10.4 Master Minimum Equipment List (MMEL)

The FAA has approved the following changes in recent revisions to the MMEL, which was posted for public comment. These changes have an impact on aircraft operators.

Because of the design change and new MCAS functional changes built into the flight-control software, dispatch with certain functions inoperative is no longer permissible. The most significant operational impact is that both FCCs must be functional for dispatch. MMEL Item 22-11-01 effectively allowed dispatch with a single FCC operative. In general, the specific changes below no longer allow dispatch of the aircraft (passenger carrying operations) with inoperative FCC, STS, certain STS warning lights, or inoperative control wheel trim switches.

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M MEL items modified or removed in submitted revision:

- 22-10-02 Autopilot Disengage Aural Warning System – the FAA will no longer allow dispatch of the Autopilot Disengage Aural Warning System (Item Removed)
- 22-11-08-01A Autopilot (A/P) Disengage Light (One Inoperative) – as a condition for dispatch, the FAA will require that the autopilot disengage aural warning system operates normally
- 22-11-10A - Control Wheel Autopilot Disengage Switches (One Inoperative) – as a condition for dispatch, the FAA will require that the Mode Control Panel autopilot DISENGAGE bar also operates normally, autopilot is not used below 1,500 feet Above Ground Level, and Approach Minimums do not require the use of autopilot
- 22-11-01 Speed Trim Function – the FAA will no longer allow dispatch with this item inoperative (Item Removed)
- 22-11-02 SPEED TRIM FAIL Light – the FAA will no longer allow dispatch with this light inoperative (Item Removed)
- 27-41-01 Control Wheel Trim Switch – the FAA will no longer allow dispatch with one of these switches inoperative (Item Removed)
- 22-10-03 STAB OUT OF TRIM Light – the FAA will no longer allow dispatch with this light inoperative (Item Removed)
- 22-10-01B Autopilot System (Item Removed)

11. Return to Service Steps

11.1 Technical Advisory Board (TAB)

11.1.1 TAB Process

The TAB, an independent team of experts, evaluated efforts by the FAA's Boeing Aviation Safety Oversight Office (BASOO), supplemented by other FAA specialists, and efforts by Boeing associated with the redesign of the MCAS. The conclusions from the TAB and resolution of the findings directly informed the FAA's decision making on MCAS.

The TAB is comprised of FAA certification specialists and chief scientific and technical advisors not involved in the original 737 MAX certification program. TAB members also include subject matter experts from the U.S. Air Force, the Volpe National Transportation Systems Center and the National Aeronautics and Space Administration (NASA).

Throughout the process, the TAB evaluated Boeing's proposed MCAS design changes by conducting design reviews, procedure evaluations and training evaluations. The TAB conducted these reviews considering representative flight conditions while maneuvering

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throughout the normal, operational and limit flight envelopes in the Boeing Engineering Simulator (eCAB). The TAB evaluations included desktop data reviews, eCAB testing and training development reviews.

The FAA reviewed Boeing’s final design documentation to evaluate compliance with all FAA regulations. The TAB also reviewed the final Boeing submission and issue a final report prior to a final determination of compliance by the FAA.

11.1.2 Findings and Dispositions

Based on the TAB’s findings in the *Report to AIR-1: Technical Advisory Board on the Design Change to the Boeing 737 MAX Maneuvering Characteristic Augmentation System* the TAB has closed and accepted the following 11 RTS action items.

Action Item	Disposition
As an extension of the TAB review, BASOO should complete an audit of Boeing’s development assurance process as documented in Boeing Document D6-86168.	Action item closed. Audit completed. The TAB evaluated and accepted the Development Assurance Accomplishment Summary document.
Boeing must submit further airplane level analysis and test data to ensure proper functional integration of the spoiler system with the trim system and MCAS	<p>The TAB further clarified that Boeing needed to include a top down assessment, or equivalent that verifies the bottom up Single & Multiple Failure (S&MF) analysis adequately covered combinations of Speed Trim System and spoiler system failures not shown to be extremely improbable.</p> <p>Action item closed. Based on TAB review of the Boeing closeout memorandum and associated reference documents. Discussion in a meeting between Boeing and the TAB on September 23, 2019 led to the creation of a document to explain how Boeing’s Airplane Functional Hazard Assessment and System Functional Hazard Assessments for the 737MAX work together to form a robust top-down analysis for airplane and system-level functions, and how that top-down analysis is verified by the bottom-up S&MF analysis. The TAB evaluated and accepted the analysis.</p>
Boeing must submit the final version of the MCAS system fault trees.	Action item closed- Boeing provided the final version of the integrated SSA dated August 25, 2020, which the TAB accepted.
Boeing must submit the complete root cause analysis for the Auto Stab Trim Monitor error in the fault tree for Low Altitude Stabilizer (design escape).	Action item closed- Boeing provided close out coordination sheet B-E325-FCS-19-024, June 19 2019 which references the root-cause analysis. The TAB reviewed and accepted the root-cause analysis.
Boeing to address the FCC CPU and memory postulated failure issue discovered during eCAB certification testing.	Item closed: The TAB evaluated new monitors to detect failures in P12.1.2 and evaluated thresholds by conducting eCAB testing. Boeing provided integrated SSA with monitor coverage dated August 25, 2020. The TAB evaluated and accepted the integrated SSA.

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Action Item	Disposition
Boeing must ensure that the SPEED TRIM FAIL procedure in the QRH encompasses both the speed trim function and the MCAS function.	Item closed: Boeing has incorporated changes in the Boeing QRH. The TAB has evaluated the changes to the Boeing QRH and found them acceptable.
Boeing must add AOA DISAGREE to the list of additional information as possible evidence of an airspeed unreliable condition in the QRH.	Item closed: Boeing has incorporated changes in the Boeing QRH. The TAB has evaluated the changes to the Boeing QRH and found them acceptable.
Boeing must submit final version of Level B training (i.e., Computer Based Training) to the TAB for review.	Item closed: The TAB reviewed all level B training and Boeing incorporated appropriate changes to the level B training as documented in the FSB report. The TAB noted that FSB report Appendix 7 requires a one-time full flight simulator training profile. The TAB recognizes the one-time training requirement, classified as "special training," was proposed by Boeing with consideration that the 737 MAX had been out of service for over one year and does not change the differences level determination and does not affect recurrent training requirements going forward for the 737 MAX.
The FAA must identify if special emphasis training for 737 series trim wheel forces awareness (including manual trim force requirement) is appropriate.	Item closed: Boeing provided and the TAB accepted Boeing Report D041A510, Revision A, 737-8/-9 Stabilizer Trim Wheel Forces, and trim awareness training per FSB report.
The FAA must change Stabilizer Trim to Speed Trim System in ATA 27 Flight Control table remarks column contained in FAA FSB report differences from base aircraft B-737-800 to B-737-8.	Item closed: The FAA incorporated the intent of the change as documented in the FSB report appendix 3 Differences Tables/Design ATA 22 Autoflight.
The Aircraft Evaluation Group (AEG) (now Aircraft Evaluation Division (AED)) to discuss with CMT and other stakeholders to consider incorporating IAS DISAGREE and AOA DISAGREE into Airspeed Unreliable Checklist so that it is titled "Airspeed Unreliable or IAS DISAGREE or AOA DISAGREE", similar to the B747 checklist.	Item closed: The TAB concluded that with the enhanced training package, pilots will be able to successfully complete the separate IAS DISAGREE and AOA DISAGREE NNCs. This was also validated in the JOEB activity and supported by B737NG service history. The TAB observes that there is a potential for confusion and misunderstanding when QRHs (or other documents) constructed by individual CAAs or operators differ from the AFM. The criteria for relief as to the extent of the customization, and the oversight of the resulting product(s), should be enhanced for AFM information that is customized for QRHs and other aircraft documents.

11.2 Service Information

The FAA reviewed and approved the service information (service bulletins) Boeing submitted that contain the design changes that address the unsafe condition and other issues relevant to the matters discussed in this report.

The agency has completed review and approved the following service information:

Boeing Alert Requirements Bulletin 737 22A1342 RB, dated November 17, 2020, describes procedures for installation of the new FCC software.

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Boeing Special Attention Service Bulletin 737-31-1860, Revision 1 dated July 2, 2020, describes procedures for installation of MDS software.

Boeing Special Attention Service Bulletin 737-27-1318, Revision 2, dated November 10, 2020, describes procedures for changing of the horizontal stabilizer trim wire routing installations.

Boeing Special Attention Service Bulletin 737-00-1028, dated July 20, 2020, describes procedures for an AOA sensor system test and an operational readiness flight.

11.3 FAA design change approval

In approving Boeing's service information and the design change, the FAA required incorporating the change into the manufacturing build of all future 737 MAX airplanes, as well as any future variants of the 737 MAX, unless the FAA later approves or mandates additional changes.

11.4 CANIC

The FAA will issue a CANIC for the 737 MAX in anticipation of issuing any MCAI in the form of an FAA AD. The CANIC provides information about the FAA's COS activities related to addressing the Lion Air Flight 610 and Ethiopian Airlines Flight 302 crashes.

11.5 Notices

The FAA published two notices to FAA inspectors containing FAA national policy on minimum required maintenance and training program changes that relate to the 737 MAX design change.

11.6 Airworthiness Directive (AD)

To mandate the design changes described in this report for airplanes that have already received a Certificate of Airworthiness or an Export Certificate of Airworthiness, the FAA issued a new AD that provides specific instructions about steps an owner or operator must take to address the unsafe condition on the 737 MAX. The AD does not apply to airplanes still under Boeing's production-approval system, which have not received an original airworthiness certification. This is because the new design is approved as part of the baseline type-certificated design and incorporates all the changes prior to first flight and approval.

The AD requires the following actions:

- Installing new FCC OPS software and doing a software installation verification.

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- Revising the existing AFM to remove the information from the applicable sections that was required by AD 2018-23-51, because that information is no longer applicable based on the design changes specified in the new AD, and to incorporate new and revised information and procedures.

The new AD also requires accomplishment of the:

- Boeing Alert Requirements Bulletin 737-22A1342 RB, dated November 17, 2020, describes procedures for installation of FCC OPS software on FCC A and FCC B, a software installation verification, and corrective actions.
- Boeing Special Attention Service Bulletin 737-31-1860, Revision 1, dated July 2, 2020, describes procedures for installation of MDS software, a software installation verification and corrective actions, and removal of certain INOP markers on the EFIS control panels.
- Boeing Special Attention Service Bulletin 737-27-1318, Revision 2, dated November 10, 2020, describes procedures for changing of the horizontal stabilizer trim wire routing installations.
- Boeing Special Attention Service Bulletin 737-00-1028, dated July 20, 2020, describes procedures for an AOA sensor system test and an operational readiness flight.

In addition, the new AD will allow dispatch of an airplane with certain inoperative systems only if certain provisions are incorporated in the operator's existing FAA-approved minimum equipment list (MEL).

12. Recommendations from Independent Panels and Other Investigative Bodies

12.1 National Transportation Safety Board (NTSB) Safety Recommendations

12.1.1 Description of Activity

The NTSB participated in the JT610 and ET302 accident investigations as the U.S. accredited representative. As a part of its responsibilities, the Board issued safety recommendations to the FAA, based on evidence and conclusions from investigative activities. On September 26, 2019, the Board issued seven safety recommendations, A-19-010 through A-19-016. The FAA has reviewed each response in relation to the 737 MAX and its readiness for return to service; however, the FAA will provide responses to the NTSB recommendations through its established processes for responding to such recommendations. The following sections provide FAA commentary on how each safety recommendation affects this airplane's return to service, and actions taken to address the identified concerns.

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12.1.2 Recommendations

Recommendation Number	Recommendation	FAA Comment
A-19-010	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 such as the MCAS, 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.	<p>The FAA has completed multiple reviews of integrated SSA for the 737 MAX, related to design changes for the MCAS specific functions, and related aspects in the stabilizer trim and autoflight systems. These design changes address causal factors related to the aircraft design as a result of the Lion Air and Ethiopian Airlines accidents, as well as additional changes to improve functionality.</p> <p>The FAA reviewed the integrated SSA and, in particular, the hazard classifications for those failure conditions with associated flight deck alerts, pilot recognition and response. The final design-change evaluation will also include a workload assessment using revised pilot procedures to minimize the potential for manufacturer assumptions to be inconsistent with pilot actions. The FAA assessed these procedures as part of an operational evaluation to ensure that appropriate procedures and training requirements are included in the project approval</p>
A-19-011	Require that for all other U.S. 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.	This safety recommendation calls for the FAA and other foreign CAAs to perform safety assessments for other transport category airplanes currently in service, similar to the safety assessment underway for the 737 MAX. The agency is currently developing its plans for assessing transport category airplane models beyond the 737 MAX and will finalize the plan once the FAA has received the reports from those open reviews.
A-19-012	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.	This safety recommendation calls for the FAA and other CAAs to perform safety assessments for other transport category airplanes currently in service similar to the safety assessment underway for the 737 MAX. The agency is currently developing its plans for assessing transport category airplane models beyond the 737 MAX and will finalize the plan once we have received the reports from those open reviews

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Recommendation Number	Recommendation	FAA Comment
A-19-013	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	Please refer to FAA Comment on recommendation A-19-016.
A-19-014	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.	Please refer to FAA Comment on recommendation A-19-016.
A-19-015	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	Please refer to FAA Comment on recommendation A-19-016.
A-19-016	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	Safety recommendations A-19-013 through A-19-016 apply to developing new tools and methodologies for validating assumptions about pilot recognition and response to safety-significant failure conditions, with associated updates to regulations and policy as necessary. The FAA will consider all similar recommendations in formulating an overarching plan for research and possible updates to the agency’s regulations, policy and guidance.

12.2 Joint Authorities Technical Review (JATR) Submittal

12.2.1 Description of Activity

The FAA Associate Administrator for Aviation Safety established the JATR to review the type certification of the flight control system on the 737 MAX. The JATR was chaired by Christopher Hart, an independent aviation safety professional and former Chairman of the NTSB. The remainder of the JATR team was comprised of 28 members from the FAA, NASA, and nine CAAs representing Australia, Brazil, Canada, China, the European Union, Indonesia, Japan, Singapore and the United Arab Emirates.

The FAA chartered the JATR to review the work conducted during the 737 MAX certification program to assess whether compliance was shown with the required

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applicable airworthiness standards related to the flight control system and its interfaces, and to recommend improvements to the certification process if warranted. Of particular concern to the FAA in chartering the JATR was the function, evaluation and certification of the MCAS function on the 737 MAX. The JATR team also focused on flightcrew training and operational suitability of the design. The JATR team considered whether the appropriate regulations and policies were applied, as well as how applicable regulations and policy material could be improved to enhance safety.

12.2.2 Recommendations

Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
1	<p>Based on the JATR team’s observations and findings related to the application of the Changed Product Rules to the certification of the flight control system of the 737 MAX, JATR team members recommend that the FAA work with other civil aviation authorities to revise the harmonized approach to the certification of changed products. Changed Product Rules (e.g., 14 CFR §§ 21.19 and 21.101) and associated guidance (e.g., AC 21.101-1B and FAA Orders 8110.4C and 8110.48A) should be revised to require a top-down approach, whereby every change is evaluated from an integrated whole-aircraft system perspective. These revisions should include criteria for determining when core attributes of an existing transport category aircraft design make it incapable of supporting the safety advancements introduced by the latest regulations and should drive a design change or a need for a new type certificate. The aircraft system includes the aircraft itself with all its subsystems, the flightcrew, and the maintenance crew.</p> <p>These Changed Product Rule revisions should take into consideration the following key principles:</p> <ul style="list-style-type: none"> ▪ A comprehensive integrated system-level analysis recognizing that in this complex interactive system, every change could interact with other parts of the system. ▪ The assessment of proposed design changes on existing systems at the aircraft level includes using DA principles, system safety principles, and validation and verification techniques. The level of assessment should be proportional to the impact of the change at the aircraft level. ▪ The consideration of training and qualification of flight and maintenance personnel, as well as detailed explicit procedures for the safe operation of the aircraft. 	<p>This recommendation is for future certification policy changes and will require research and coordination with other CAAs. In relation to the FAA’s approval of Boeing’s 737 MAX current design changes, the agency’s analysis included extensive evaluation of the integrated System Safety Analyses, including interaction between systems, a thorough review of design assurance processes, and a detailed examination and testing for appropriate training requirements.</p>

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Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
2	Based on the JATR team’s observations and findings related to the regulations, policy, and compliance methods applied to the 737 MAX, JATR team members recommend that the FAA update regulations and guidance that are out of date and update certification procedures to ensure that the applied requirements, issue papers, means of compliance, and policies fully address the safety issues related to state-of-the-art designs employed on new projects. JATR team members also recommend that the FAA review its processes to ensure that regulations and guidance materials are kept up to date.	This recommendation is for future certification policy changes and will require research and coordination with other CAAs.
3	Based on the JATR team’s observations and findings related to the certification of the 737 MAX flight control system and related interfaces, JATR team members recommend that the FAA review the 737 MAX compliance with 14 CFR 25.1329 (Flight Guidance System), 25.1581 (Airplane Flight Manual – General), and 25.201 (Stall Demonstration) and ensure the consistent application and interpretation of regulatory guidance material for the system safety assessment, handling qualities rating method, and conformity requirements for engineering simulators and devices. Should there be a non-compliance, the root cause should be identified and measures implemented to prevent recurrence.	The FAA’s approval of the 737 MAX current design changes included extensive evaluation of 737 MAX compliance to 14 CFR 25.1329 (Flight Guidance System), 25.1581 (Airplane Flight Manual – General), and 25.201 (Stall Demonstration). Analysis and tests were conducted on FCC software changes, procedural changes included in the AFM and in addition, flight testing for stall characteristics. The FAA routinely reviews application of technical policy and will review compliance issues with these regulations to determine whether regulatory and policy changes are required.
4	Based on the JATR team’s observations and findings related to the FAA type certification process, JATR team members recommend that the FAA review and update guidance pertaining to the type certification process with particular emphasis on early FAA involvement to ensure the FAA is aware of all design assumptions, the aircraft design, and all changes to the design in cases where a changed product process is used. The FAA should consider adding feedback paths in the process to ensure that compliance, system safety, and flight deck/human factors aspects are considered for the aircraft design throughout its development and certification.	This recommendation is for future certification policy changes and will require research and coordination with other CAAs. In relation to FAA approval of the 737 MAX current design changes, Boeing involved the FAA from the beginning of the design-change effort and the FAA did not delegate any compliance findings to the Boeing Organization Designation Authorization (ODA). In addition, the FAA supplemented BASOO resources with staff from other offices within the FAA to accomplish the depth of review

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Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
5	<p>Based on the JATR team’s observations and findings related to the FAA’s oversight by the BASOO, JATR team members recommend that the FAA conduct a workforce review of the BASOO engineer staffing level to ensure there is a sufficient number of experienced specialists to adequately perform certification and oversight duties, commensurate with the extent of work being performed by Boeing. The workforce levels should be such that decisions to retain responsibility for finding compliance are not constrained by a lack of experienced engineers. The FAA should review the Boeing ODA work environment and ODA manual to ensure the Boeing ODA engineering unit members (E-UMs) are working without any undue pressure when they are making decisions on behalf of the FAA. This review should include ensuring the E-UMs have open lines of communication to FAA certification engineers without fear of punitive action or process violation .</p>	<p>This recommendation is for future certification policy changes and will require research by the newly established ODA Office under the FAA’s Office of Aviation Safety (AVS). In relation to the FAA’s approval of the 737 MAX current design changes, the FAA delegated no compliance findings to the Boeing ODA. In addition, the FAA supplemented BASOO resources with staff from other offices within the FAA. The additional resources compliment and expand the 737 MAX project team’s knowledge, skills and abilities relative to Boeing’s design change.</p>
6	<p>Based on the JATR team’s observations and findings related to the design process of the flight control system and the related system safety assessments for the 737 MAX, JATR team members recommend that the FAA promote a safety culture that drives a primary focus on the creation of safe products, which in turn comply with certification requirements. Aircraft functions should be assessed, not in an incremental and fragmented manner, but holistically at the aircraft level. System function and performance, including the effects of failures, should be demonstrated and associated assumptions should be challenged to ensure robust designs are realized. The safety analysis process should be integrated with the aircraft DA process to ensure all safety requirements and associated assumptions are correct, complete, and verified. The FAA should encourage applicants to have a system safety function that is independent from the design organization, with the authority to impartially assess aircraft safety and influence the aircraft/system design details. Adoption of a safety management system is one way this can be achieved.</p>	<p>This recommendation is for future changes to Boeing and FAA interaction policy and will require research and coordination. In relation to FAA’s approval of the 737 MAX current design changes, the FAA addressed the impact of the JATR findings by implementing a higher degree of involvement in the design change evaluation and did not delegate any compliance findings to the Boeing ODA.</p>

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Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
7	<p>Based on the JATR team’s observations and findings related to human factors-related issues in the certification process, JATR team members recommend that the FAA integrate and emphasize human factors and human system integration throughout its certification process. Human factors-relevant policies and guidance should be expanded and clarified, and compliance with such regulatory requirements as 14 CFR §§ 25.1302 (Installed Systems and Equipment for Use by the Flightcrew), 25.1309 (Equipment, Systems, and Installations), and 25.1322 (Flightcrew Alerting) should be thoroughly verified and documented. To enable the thorough analysis and verification of compliance, the FAA should expand its aircraft certification resources in human factors and in human system integration.</p>	<p>This recommendation is for future certification policy changes and will require research and coordination with other CAAs. The FAA’s approval of the 737 MAX current design changes included extensive evaluation of documentation and compliance to 14 CFR §§ 25.1302 (Installed Systems and Equipment for Use by the Flightcrew), 25.1309 (Equipment, Systems, and Installations), and 25.1322 (Flightcrew Alerting). The FAA assigned human factors specialists to the TAB from outside the agency to help evaluate human factors of the design change.</p>
8	<p>Based on the JATR team’s observations and findings related to the DA process applied to the design of the flight control system of the 737 MAX, JATR team members recommend that the FAA ensure applicants apply industry best practices for development assurance, including requirements management, visibility of assumptions, process assurance activities, and configuration management. The FAA should ensure achievement of the close coupling that is required between the applicant safety analysis process and the DA process to classify failure conditions and derive the level of rigor of design development and verification. A current example of an industry best practice is SAE International’s ARP 4754A (ARP4754A). The FAA should review and amend AC 20-174 to clearly articulate the principles of ARP4754A, promoting industry best practice for DA of aircraft and aircraft systems to address applicants’ design trend of increasing integration between aircraft functions and systems.</p>	<p>Consistent with the TAB recommendation, a joint audit was conducted on the initial software development process, and on the final production FCC software, by the FAA and EASA. The FAA’s approval of the 737 MAX current design changes included extensive evaluation of the company’s DA process applied to the design of the flight control system, including requirements management, visibility of assumptions, process assurance activities, and configuration management. Process improvements based on lessons learned would support future certification policy changes and will require research and coordination with other CAAs.</p>
9	<p>Based on the JATR team’s findings and observations related to the operational design assumptions of crew response applied during the certification process for the flight control system of the 737 MAX, JATR team members recommend that the FAA require the integration of certification and operational functions during the certification process. The FAA should be provided all system differences between related aircraft in order to adequately evaluate operational impact, systems integration, and human performance.</p>	<p>This recommendation is for future operational evaluation policy changes and will require research and coordination between FAA organizations. The FAA’s approval of the 737 MAX current design changes included extensive coordination with senior leadership from offices responsible for continued airworthiness, certification of the design change, and operational evaluation.</p>

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Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
10	Based on the JATR team’s findings and observations related to flightcrew training, JATR team members recommend that the FAA require a documented process to determine what information will be included in the AFM, the Flightcrew Operating Manual, and the Flightcrew Training Manual (FCTM). The FAA should review training programs to ensure flightcrews are competent in the handling of mistrim events.	This recommendation is for future certification policy changes and will require research and coordination with other civil aviation authorities. In relation to the FAA’s approval of the 737 MAX current design changes, the FAA’s certification offices and operational evaluation offices conducted extensive analysis and testing, including the JOEB process to determine adequacy of the AFM and FCTM content. All affected procedures (checklists) were included in the AFM.
11	JATR team members recommend that the FAA conduct a study to determine the adequacy of policy, guidance, and assumptions related to maintenance and ground handling training requirements.	This recommendation is for future maintenance and ground handling policy changes and will require research and coordination with other CAAs.
12	JATR team members recommend that the FAA review its policies for analyzing safety risk and implementing interim AD action following a fatal transport aircraft accident. The FAA should ensure that it shares post-accident safety information with the international community to the maximum extent possible.	This recommendation is for future continued airworthiness policy changes and will require research and coordination with other civil aviation authorities. The FAA recognizes the value of sharing information with the international community, by evidence of this report.

12.3 JT610 Final Accident Report

12.3.1 Description of Activity

On October 25, 2019, the KNKT released the final report for PT. Lion Mentari Airlines Boeing 737 MAX; PK-LQP, also known as Flight JT610 in this document. The report is based on the investigation the KNKT conducted in accordance with Annex 13 to the Convention on International Civil Aviation, the Indonesian Aviation Act (UU No. 1/2009) and Government Regulation (PP No. 62/2013). The FAA and Boeing supplied technical advisors to the NTSB, which assisted the KNKT. The KNKT final report documents a comprehensive investigation that probed circumstances that led to the accident, including airplane design, certification, operations and maintenance. Other areas reviewed include component repair and oversight, air traffic control, pilot training and airline safety programs.

The KNKT report includes safety recommendations for several groups. This report includes all KNKT recommendations for Boeing, Xtra Aerospace and the FAA. The FAA notes, however, that the KNKT final report includes a wide range of recommendations for air traffic, operations, maintenance and others. The FAA did not address recommendations outside of the aircraft design and related training, maintenance and operational

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documents. However, the FAA believes those recommendations should be addressed by the appropriate organizations, outside of the effort addressed in this report.

12.3.2 Recommendations

Recommendation Number	Recommendation	Analysis for Impact to 737 MAX RTS
04.O-2018-35.10 Xtra Aerospace	<p>After Xtra Aerospace repair of the accident AOA sensor in November of 2017, the sensor was installed on the PK-LQP aircraft on left side position during the maintenance activity in Denpasar on October 28, 2018. On the subsequent flight, a 21-degree difference between left and right AOA sensors was recorded on the digital flight data recorder (DFDR), commencing shortly after the takeoff roll was initiated. This immediate 21- degree delta indicated that the AOA sensor was most likely improperly calibrated at Xtra. As noted, utilization of the Peak Model SRI-201B API by Xtra Aerospace for the test and calibration of the 0861FL1 AOA sensor should have required a written procedure to specify the proper position of the REL/ABS switch. Therefore, KNKT recommends emphasizing the implementation of a company manual including equivalency assessment, training and written procedure, to ensure component being repaired are properly maintained.</p>	<p>On October 24, 2019, the FAA revoked Xtra’s Title 14 CFR part 145 Air Agency certificate. The FAA primarily based the revocation on the fact that after performing maintenance, Xtra systemically approved articles for return to service when some of the articles were not listed on its capability list. Xtra did so without conducting self-evaluations to determine whether it had the appropriate and equivalent test equipment/tooling capability.</p>
04.R-2018-35.11 Boeing	<p>During flight JT610, multiple alerts and indications occurred which increased flightcrew’s workload. This obscured the problem and the flightcrew could not arrive at a solution during the initial or subsequent automatic AND stabilizer trim input, such as performing the runaway stabilizer procedure or continuing to use electric trim to reduce column forces and maintain level flight. Therefore, KNKT recommends that the aircraft manufacture consider the effect of all possible flight deck alerts and indications on flightcrew recognition and response; and incorporate design, flightcrew procedures, and/or training requirements where needed to minimize the potential for flightcrew actions that are inconsistent with manufacturer assumptions.</p>	<p>Development and certification activity to return the 737 MAX to service addressed this recommendation. Boeing proposed design changes and worked with the FAA to assess and revise flight deck alerts, flightcrew responses, procedures, and training consistent with this KNKT recommendation.</p>

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Recommendation Number	Recommendation	Analysis for Impact to 737 MAX RTS
04.R-2018-35.12 Boeing	During certification phase, flight test pilots, who normally have exceptional skill and experience, are used to demonstrate compliance. Flight test pilots generally have more knowledge about the aircraft design characteristics than normal pilots do. Flight test pilots however, are trained to replicate the average flightcrew. The Aircraft Evaluation Group pilots, who have an operational flying background, also evaluate the aircraft during the certification phase. These pilots establish the pilot type rating, training, checking and currency requirements as part of the Flight Standardization Board (FSB) process. The FSB process also utilizes airline line pilots to help ensure the requirements are operationally representative. The FAA and OEMs should re-evaluate their assumptions for what constitutes an average flightcrew’s basic skill and what level of systems knowledge a ‘properly trained average flightcrew’ has when encountering failures. Therefore, KNKT recommends that Boeing include a larger tolerance in the design is required to allow operability by a larger population of flight-rated pilots.	Development and certification activity to return the 737MAX to service addressed this recommendation. Boeing was mindful during the redesign of MCAS and associated systems that new design must not require exceptional pilot skills or capabilities. The criteria has not changed, but the new MCAS system design allows for a wide range of piloting techniques (e.g. short vs. long duration trim inputs). Rather than relying on crew procedures, the new design is such that the need for using the Stabilizer Runaway Non Normal Checklist will be extremely improbable. The procedure still exists, but should never be needed.
04.M-2018-35.13 Boeing	During the accident flight, the DFDR recorded a control force of 103 lbs., after repetitive MCAS activation was responded to by the First Officer with inadequate trim to counter MCAS. At this point, the flightcrew was unable to maintain altitude. Therefore, KNKT recommends that Boeing and the FAA more closely scrutinize the development and certification process for systems whose malfunction has the ability to lead to loss of control of the airplane.	Development and certification activity to return the 737 MAX to service addressed this recommendation. The redesigned MCAS system will not be prone to either erroneous or repeat activations. Furthermore, the design limits the magnitude of an MCAS command so the pilot retains sufficient elevator control to counter the MCAS generated stabilizer input, based on flight conditions.
04.M-2018-35.14 Boeing	The flightcrew should have been provided with information and alerts to help them understand the system and know how to resolve potential issues. Flightcrew procedures and training should be appropriate. Therefore, KNKT recommends that Boeing develop guidance for the criteria of information which should be included in flightcrew’s and engineer’s manuals.	This recommendation is specific to development of guidance. The guidance is not required for RTS. For the RTS certification review, the FAA was actively involved in determining the information that would be included in flightcrew and engineer manuals.
04.R-2018-35.15 Boeing	The aircraft should have included the intended AOA DISAGREE alert message functionally, which was installed on 737 NG aircraft. Boeing and the FAA should ensure that new and changed aircraft design are properly described, analyzed, and certified. Therefore, KNKT recommends to Boeing that they ensure that certified and delivered airplanes have intended system functionality.	Development and certification activity to address the safety issues on the 737 MAX addressed this recommendation. The AOA DISAGREE message will be basic and functional on all 737 MAX airplanes as they return to service

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Recommendation Number	Recommendation	Analysis for Impact to 737 MAX RTS
04.R-2018-35.16 Boeing	The IFIM tasks of “ALT DISAGREE” and “IAS DISAGREE” are duplicated on the leak test in step (3) and (4) as they are referring to the same AMM tasks. This repetition was inefficient and did not contribute to problem solving. Therefore, KNKT recommends the IFIM tasks sequence are reviewed to ensure they are effective.	Development and certification activity to address the safety issues on the 737 MAX addressed this recommendation. The IFIM document was reviewed/ revised on November 15, 2019 to remove the repetitive tasks.
04.R-2018-35.20 FAA	In the accident flight, the system malfunction led to erroneous information that initiated a series of events that were not correctly recognized and responded to by the flightcrew. This exposed issues that were not identified if Federal Aviation Regulation (FAR) 25.1302 and 25.1309 were each considered separately. There could be a potential gap between the two requirements when system malfunction is followed by crew fallibility. Therefore, KNKT recommends that FAA review the requirements of the applicable FARs to consider any issue that may be overlooked when the requirements are considered separately.	This recommendation is for future certification policy changes and will require research and coordination with other civil aviation authorities. Development and certification activity to address the safety issues of the 737 MAX addressed this recommendation. The FAA’s review of the 737 MAX current design changes included extensive evaluation of documentation and compliance with 14 CFR §§ 25.1302 (Installed Systems and Equipment for Use by the Flightcrew), 25.1309 (Equipment, Systems, and Installations), and 25.1322 (Flightcrew Alerting). The FAA assigned human factors specialists to the TAB from outside the agency to help evaluate human factors of the design change.
04.R-2018-35.21 FAA	In the accident flight, the system malfunction led to a series of aircraft and flightcrew interactions which the flightcrew did not understand or know how to resolve. It is the pilot response assumptions in the initial design process which, coupled with the repetitive MCAS activations, turned out to be incorrect and inconsistent with the Functional Hazard Assessment classification of Major. Therefore, the KNKT recommends that the FAA review their processes for determining their level of involvement (degree of delegation) and how changes in the design are communicated to the FAA to ensure an appropriate level of review.	This recommendation is for future Boeing and FAA interaction policy changes and will require research and coordination. In relation to the FAA’s review of the 737 MAX current design changes, the FAA addressed the impact of these recommendations by implementing a higher degree of involvement in the design change evaluation and did not delegate any compliance findings to the Boeing ODA.
04.R-2018-35.22 FAA	The absence of equivalency assessment required by Xtra Aerospace procedure and unavailability of procedure was not detected by the FAA. This indicated inadequacy of FAA oversight. Therefore, KNKT recommends that FAA improve the oversight of Approved Maintenance Organization (AMO) to ensure the processes within the AMO are conducted in accordance with the requirements.	This recommendation is for future maintenance and ground-handling policy changes and will require research and coordination with other CAAs. The FAA addressed relevant activity at Xtra Aerospace in a separate action from its activities to address the safety issues on the 737 MAX.

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Recommendation Number	Recommendation	Analysis for Impact to 737 MAX RTS
04.R-2018-35.23 FAA	During the accident flight, the DFDR recorded a control force of 103 lbs., after repetitive MCAS activation was responded to by the First Officer with inadequate trim to counter MCAS. At this point, the flightcrew was unable to maintain altitude. Therefore, KNKT recommends that Boeing and the FAA more closely scrutinize the development and certification process for systems whose malfunction has the ability to lead to loss of control of the airplane.	This recommendation is for future certification policy changes and will require research and coordination with other CAAs. The FAA’s review of the 737 MAX current design changes included extensive evaluation of documentation and compliance with 14 CFR §§ 25.1302 (Installed Systems and Equipment for Use by the Flightcrew), 25.1309 (Equipment, Systems, and Installations), and 25.1322 (Flightcrew Alerting). The FAA assigned human factors specialists to the TAB from outside the agency to help evaluate human factors of the design change.
04.R-2018-35.24 FAA	During the accident and previous LNI043 flights, the flightcrew initially responded in the same way, by pulling back on the control column. However, they did not consistently trim out the resulting column forces as had been assumed. As a result Boeing’s assumption regarding pilot behavior and reaction time was different from the pilot behavior and reaction time in responding to MCAS activation. Therefore, the KNKT recommends that the FAA work with international regulatory authorities to review assumptions on pilot behavior used during design and revise certification processes to ensure assumptions used during the design process are validated.	This recommendation is for future certification policy changes and will require research and coordination with other CAAs. The FAA’s review of the 737 MAX current design changes included extensive evaluation of documentation and compliance to 14 CFR §§ 25.1302 (Installed Systems and Equipment for Use by the Flightcrew), 25.1309 (Equipment, Systems, and Installations), and 25.1322 (Flightcrew Alerting). The FAA assigned human factors specialists to the TAB from outside the agency to help evaluate human factors of the design change.
04.R-2018-35.25 FAA	The flightcrew should have been provided with information and alerts to help them understand the system and know how to resolve potential issues. Flightcrew procedures and training should be appropriate. Therefore, KNKT recommends to the FAA work with international regulatory authorities to review the guidance for the criteria of information which should be included in flightcrew and engineer’s manuals.	This recommendation is for future certification policy changes and will require research and coordination with other CAAs. In relation to the FAA’s review of the current design changes, the FAA’s certification offices and operational evaluation offices conducted extensive analysis and tests, and used the JOEB process to determine adequacy of the AFM and FCTM content. All affected procedures (checklists), changed or unchanged, are included in the AFM.
04.R-2018-35.26 FAA	The aircraft should have included the intended AOA DISAGREE alert message functionally, which was installed on 737 NG aircraft. Boeing and the FAA should ensure that new and changed aircraft design are properly described, analyzed, and certified. Therefore, KNKT recommends to Boeing and the FAA that they ensure that certified and delivered airplanes have intended system functionality	The current design change for the 737MAX requires installation of an update Multi-Function Display software to assure AOA DISAGREE annunciation logic has been updated to maintain commonality between the 737 NG and the 737 MAX families of aircraft.

Summary of the FAA’s Review of the Boeing 737 MAX

Recommendation Number	Recommendation	Analysis for Impact to 737 MAX RTS
04.R-2018-35.27 FAA	<p>The aircraft was equipped with an airframe-mounted low frequency Underwater Locator Beacon (ULB) which operated at a frequency of 8.8 kHz. The beacon is included in ICAO standards. The purpose of the beacon is to aid in the location of submerged aircraft. During the search phase, multiple surveys were conducted to detect a signal at 8.8 kHz, however no such signals were detected in the area where wreckage was recovered. The beacon was mounted on the forward side of the nose pressure bulkhead. Most of the preferred installation locations could not be used because they proved to be incompatible with EASA and FAA Non-Rechargeable Lithium Battery certification requirements or they did not meet the ICAO empennage and wings exclusion. Therefore, KNKT recommends to the FAA work with international regulatory authorities to review the requirements for installation of Non-Rechargeable Lithium Battery certification requirements.</p>	<p>This recommendation is for future certification policy changes and will require research and coordination with other CAAs.</p>

Summary of the FAA’s Review of the Boeing 737 MAX

Recommendation Number	Recommendation	Analysis for Impact to 737 MAX RTS
<p>Notable Entry (Not a KNKT recommendation)</p>	<ul style="list-style-type: none"> • In section 1.16.1 Installation Test AOA Sensor with Known Bias, the KNKT investigated the adequacy of the AOA Sensor installation instructions. • “On 15 November 2018, with approval from KNKT and under direction and supervision of the NTSB, Boeing and the NTSB conducted an installation test of an AOA sensor on an exemplar the 737 MAX located at the Boeing Field Flight Line. This test was intended to demonstrate if the AMM installation test, task 34-21-05-400-801, was robust enough to ensure that a bias in an AOA sensor could be identified/detected using the installation and alternate test procedure. The tests conducted as follow: <ol style="list-style-type: none"> 1. The tests were conducted on a production 737 MAX aircraft in serviceable condition inside a hangar with adequate lighting. 2. The first test consisted of installing a known serviceable AOA sensor in the left position of the aircraft on the production aircraft. 3. The second test consisted of installing an AOA sensor with an induced or known bias of approximately 33° (modified to have 33° bias) in the left position of the aircraft. 4. The tests were done with and without entering good weight data into the flight management computer. • Conclusion: <ol style="list-style-type: none"> 1. With the serviceable (original) AOA sensor installed on the aircraft, the results of the alternative installation test indicated that the left AOA sensor met the AMM requirements. 2. With the biased AOA sensor, the test found that the vane angle values exceed the limits as follows: a. when the vane was at its zero position, the SMYD displayed -31.9° (the misalignment angle) instead of 0° ± 5° b. When the vane positioned at its maximum upper stop, the SMYD displayed +67.6° instead of +100° ± 5°. c. When the vane positioned at its maximum lower stop, the SMYD displayed the text “AOA SENSR INVALID”. 3. The alternative method of the installation test in the AMM will successfully detect a mis-calibrated AOA sensor.” 	<p>The FAA reviewed the results of this test of the adequacy of the AOA Sensor installation instructions and determined the existing AMM instructions are satisfactory and require no change. As part of the return to service activity the FAA expects that it will require that AOA Sensor installation checks be conducted on all 737 MAX aircraft.</p>

12.4 U.S. Department of Transportation Special Committee

12.4.1 Description of Activity

In April 2019, U.S. Secretary of Transportation Elaine L. Chao created the Special Committee to Review the Federal Aviation Administration’s Aircraft Certification Process (the Committee). The Committee was commissioned as an independent panel of aviation and safety experts to conduct an objective review of the FAA’s procedures for product certification and the processes the FAA and Boeing followed during the certification of the 737 MAX. The Committee was instructed to review the certification process, evaluate potential enhancements to the system, and make recommendations to bolster aviation safety.

12.4.2 Recommendations

Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
1- Safety Management Systems	<p>Safety Management Systems (SMS) help to ensure a holistic, proactive assessment of whether the combination of design, procedures, and training will support effective safety performance. There is no requirement for SMS for design and manufacturing organizations. The FAA currently requires an SMS only for part 121 operators.</p> <p>The FAA must mandate implementation of SMS for design and manufacturing organizations, thereby ensuring connection and interrelationship with the existing SMSs of airlines, airports, and service providers.</p> <p>The FAA should take the necessary steps to ensure a total system approach to safety, linking all safety requirements from type certification to pilot training, and operational performance of the product.</p> <p>The FAA should encourage the integration of Partnership for Safety Plan PSP, SMS, and ODA activities to create an effective oversight process to better manage safety and certification issues.</p>	<p>This recommendation is for future SMS policy changes. The FAA encourages and recognizes voluntary SMS programs for manufacturers. The FAA has initiated a rulemaking effort to require manufacturers to have an SMS program.</p>

Summary of the FAA’s Review of the Boeing 737 MAX

<p>Recommendation Number</p>	<p>Recommendation</p>	<p>Analysis for impact to 737 MAX RTS</p>
<p>2- System Safety</p>	<p>SSAs are an essential component of safety risk management that can be expanded to better consider human-machine interaction. The FAA and industry should review requirements and guidance materials to promote more consistent use of systematic analysis of Human Performance and Error Assessments to complement SSAs in aircraft certification. The FAA should consider removing exclusions for skill-related errors associated with manual control of the airplane and ensure crew interaction with automated systems active in manual flight are systematically assessed. Current guidelines recommend that human factors be considered when the system is new or novel, complex and/or integrated.</p> <p>In the future, the FAA should enhance standards to ensure that systematic human factor analyses are conducted for all safety-critical functions and failure modes associated with a change under the changed product rule (14 CFR § 21.101). Test and evaluation should include multiple failure mode scenarios and involve trained pilots who reflect the anticipated end-users of the product. Resulting data should be fed back into the overall safety assessment of the total system. Significant changes to safety assumptions or performance levels should be tracked. A summary document explaining SSA assumptions and conclusions relevant to safe operation should be communicated throughout the development process and to end-users of the product as reference data for an operator’s SMS program. End users should be required to monitor leading indicators to validate the assumptions of the SSA once the product enters service.</p>	<p>This recommendation is for future certification policy changes and will require research and coordination with other CAAs. In relation to the FAA’s review of the 737 MAX current design changes, the certification effort has included extensive evaluation of the integrated System Safety Analyses including interaction between systems, a thorough review of design assurance processes, and a detailed examination and testing for appropriate training requirements.</p>

Summary of the FAA’s Review of the Boeing 737 MAX

Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
3-Globalization	<p>Although U.S. products are operating worldwide, the FAA does not have a means to influence the maintenance and pilot training requirements for U.S. products operating under another civil aviation authority. The FAA should acknowledge the international profile of operators of U.S. State of Design aircraft and implement the necessary changes for its aircraft certification system to consider differences in operations, training, and oversight across States. Some members of the international community are using the FSB reports intended for U.S. operators as the foundation for their operational programs, which was not their intended purpose. The FAA, therefore, should consider including operational requirements as part of the type certificate in order to better communicate minimum standards and promote advanced training and qualification programs. This would allow transfer of operational and training requirements through the validation process. The FAA should expand its engagement, policies, technical assistance, and training efforts to foster higher international safety standards and practices for aircraft certification, operations, and maintenance</p>	<p>This recommendation is for future international coordination and support of operations and will require research and collaboration with other CAAs. For the 737 MAX, the FAA conducted extensive analysis and testing to establish appropriate training requirements. The FAA provided the FSB report along with all other relevant information to the international community. The agency plans to support its international partners with frequent communications to assure all operators and CAAs are fully informed</p>
4-Data	<p>Aviation safety would be bolstered by better data gathering, targeted analysis of aviation data by experts, and the use of all available data for developing and implementing corrective actions to mitigate risk. Operational data needs to be made available in a single repository for analysis. To this end, the FAA and industry stakeholders of the certification system should continue to develop a means for expeditious gathering and analyzing, and acting on large quantities of operational data and reporting de-identified results to the aviation community, using Aviation Safety Information Analysis and Sharing as an example. The FAA should propose to ICAO the sharing of operational data internationally, to enhance safety initiatives. The FAA should find a way to integrate de-identified and confidential data sources so that the aircraft certification workforce, Flight Standards inspectors and other safety organizations can focus on near-time risk factors as part of their COS activities. The FAA should continue working with NASA to develop an in-time aviation safety management system that can be used both by the regulator and industry.</p>	<p>This recommendation is for future certification policy changes and will require research and development.</p>

Summary of the FAA’s Review of the Boeing 737 MAX

Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
<p>5- Coordination between the FAA’s Aircraft Certification Service (AIR) and FAA’s Flight Standards Service (AFX)</p>	<p>AIR develops and manages the aircraft certification process, which involves personnel from AFX—a separate organization with its own policies, guidance, leadership, and culture. The potential exists for a disconnect between design and operational requirements. The FAA should review and clarify the roles and responsibilities of the Aircraft Evaluation Group (AEG) (now Aircraft Evaluation Division (AED)) in the product certification process to define objectives, precise engagement, and timing throughout the process. This process should include a review of the working relationship between AFX and AIR to ensure that AEG (now AED) representatives are engaged early enough in the certification process to review operational safety requirements and oversee assessments of design features and assumptions affecting operations. The AEG (now AED) should have sufficient engagement throughout the process to be aware of any design changes that occur after the first certification plan is executed. Clarifications should be reflected in policy and guidance materials, which should also be evaluated to determine which organizations should be responsible for them.</p>	<p>This recommendation is for future continuous improvement in the AIR/AED coordination process. The AED has been extensively engaged throughout the 737 MAX RTS certification process, as a core team member supporting the Flightcrew Operations Testing, and leading the FSB.</p>
<p>6-Personnel</p>	<p>The FAA cannot accommodate the growth and complexity in certification workload without effectively understanding and managing its personnel requirements and influencing cultural changes in the workforce to adapt to the changing nature of the work. Priorities include proper skill identification, skill development, and attracting the right talent. The FAA should plan an aggressive recruitment campaign to encourage students to pursue careers at the FAA. The FAA should re-evaluate its current position descriptions and desired skill sets—especially as they relate to covering systems and process knowledge—to ensure that personnel with the right range of skills occupy safety-critical positions so that the agency can meet evolving industry needs. Workforce planning is not just about hiring new people; it is also about filling the gaps between what the FAA currently has and what it needs and making effective use of current staff. AVS should re-evaluate its workforce strategy to ensure it is sufficient to accomplish the AIR transformation and adapt with ever-changing global aviation industry.</p>	<p>This recommendation concerns future personnel program and initiative enhancements. Focus areas include expanded recruiting and workforce development, targeting safety critical positions and emphasizing systems thinking. In relation to the 737 MAX safety-review effort, the FAA supplemented BASOO resources with experienced staff from other offices within the FAA. The additional resources compliment and expand the 737 MAX project team’s knowledge skills and abilities relative to Boeing’s design change.</p>

Summary of the FAA’s Review of the Boeing 737 MAX

Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
7-Delegation	<p>The FAA’s delegation system is an appropriate and effective tool for conducting aircraft certification. It relies on effective standards, oversight, and communication between stakeholders. The aviation community, including the FAA, industry, stakeholders, and Congress, should recognize that the delegation system allows U.S. industry and innovation to thrive, while allocating FAA resources to derive the greatest safety benefit. The FAA should continue to make use of the current delegation system, which is solidly established, well controlled, and promotes safety through effective oversight. The FAA and industry should work together to address concerns about potential undue pressure on an ODA Unit in order to maintain the independent decision-making structure of the ODA and ensure that the ODA fulfills its requirement to serve as a representative of the FAA Administrator. The FAA should ensure that its personnel involved in overseeing designees evolve in step with the delegation system. Oversight of a delegated organization is not the same as oversight of a delegated individual, and requires a specific skill set related to systems thinking. A continued focus on change management is needed to empower FAA staff and enable them to adapt to a changing work landscape. The FAA should provide clarification and guidance on how and when FAA technical specialists and ODA unit members communicate directly regarding technical concerns.</p>	<p>This recommendation is for future certification policy changes and will require research by the newly established ODA Office under AVS. In relation to the FAA’s approval of the 737 MAX current design changes, the FAA delegated no compliance findings to the Boeing ODA. In addition, the FAA supplemented BASOO resources with staff from other offices within the FAA. E-UMs were also involved in the process with the FAA engineering staff.</p>
8- Amended Type Certificates	<p>The FAA evaluates an application for an amended type certificate using the same structured process as for a new type certificate, and both processes result in certification of a safe product. In fact, the ability to change a TC is important and promotes an increase in safety for derivative models that replace aging airplanes. The FAA should work to ensure FAA policy and guidance are updated to include cross-system (equipment, human, and environment) evaluation of changes. The FAA should update existing guidance to highlight the vulnerabilities that can develop around multiple adaptations of existing systems, where transfer of historical assumptions may not be appropriate or may require specific validation. This can be relevant to new TC programs, but is more likely relevant to amended TC programs where system integration can have unique challenges. The FAA should clarify roles and responsibilities of the applicant and FAA in assessing cross-functional interface assumptions in determining what constitutes a significant change.</p>	<p>This recommendation is for future certification policy changes and will require research and coordination with other civil aviation authorities. In relation to the FAA’s review of the 737 MAX current design changes, the certification effort has included extensive evaluation of the design assurance processes, the integrated SSA including multi-systems interaction and a detailed examination and testing for appropriate training requirements.</p>

Summary of the FAA’s Review of the Boeing 737 MAX

Recommendation Number	Recommendation	Analysis for impact to 737 MAX RTS
9-Innovation	AIR focuses its innovation work on guidance materials, standards, and regulations to support new entrants into the aviation market. Since the Innovation Center is a recently adopted concept, AIR should provide guidance expeditiously to both its employees and the industry on how the center will operate and expectations for success. The Innovation Center must include and encourage review of innovative methods of compliance to previously certified systems. The Innovation Center R&D portfolio should include and prioritize changes to the certification process and regulatory framework so that the FAA’s certifying system can keep up with concepts and technologies in the products it certifies. FAA should continue implementation of performance-based regulations for the adoption of new technologies that do not stifle future innovations.	This recommendation is for future organizational, procedural and policy changes for the AIR Center for Emerging Concepts and Innovation.

13. FAA Conclusion

Following a thorough, transparent and inclusive process, the FAA determined that Boeing’s changes to the 737 MAX design, flightcrew procedures and maintenance procedures effectively mitigate the airplane-related safety issues that contributed to the Flight 610 and Flight 302 accidents. The FAA further determined that the design change addressed additional safety concerns beyond those identified during the accident investigations. This report does not address other safety issues that might have contributed to the accidents but are not related to airplane design, including maintenance, aircraft operator and air traffic control. The FAA believes recommendations related to these other potential contributing factors should be addressed by the appropriate organizations. Further, the FAA evaluated Boeing’s proposed flightcrew training through the Flight Standardization Board process. The FAA issued a final Boeing 737 Flight Standardization Board Report documenting the results of the operational evaluation.

13.1 Safety Issue #1: Use of Single Angle of Attack (AOA) Sensor

In the original design, erroneous data from a single AOA sensor activated MCAS and subsequently caused airplane nose-down trim of the horizontal stabilizer. In the new design, Boeing eliminated MCAS reliance on a single AOA sensor signal by using both AOA sensor inputs and through flight-control law changes that include safeguards against failed or erroneous AOA indications. The updated FCC software with revised flight-control laws uses inputs from both AOA sensors to activate MCAS. This is in contrast to the original MCAS design, which relied on data from only one sensor at a time, and allowed repeated MCAS activation as a result of input from a single AOA sensor. The updated FCC software compares the inputs from the two sensors to detect a failed AOA sensor. If the difference

between the AOA sensor inputs is above a calculated threshold, the FCC will disable the STS, including its MCAS function, for the remainder of that flight and provide a corresponding indication of such deactivation on the flight deck.

13.2 Safety Issue #2: MCAS Reset Generates Repetitive MCAS Commands

In the original design, when a continuous erroneous high AOA sensor value existed, the MCAS control law used pilot release of the electric trim switch to reset MCAS activation. Once reset, the MCAS system would make another airplane nose-down stabilizer trim command after five seconds. This scenario would repeat each time the MCAS made a command and the pilot made an electric trim command of any duration and released the trim switch. In the new design, Boeing included flight-control law changes to ensure that MCAS will not command repeated movements of the horizontal stabilizer. The revised flight-control laws allow only one activation of MCAS per sensed high-AOA event. A subsequent activation of MCAS is only possible after the airplane returns to a low-AOA state, below the threshold that would cause MCAS activation.

13.3 Safety Issue #3 MCAS Trim Authority

In the original design, all MCAS commands were incremental commands, which moved the horizontal stabilizer a fixed amount regardless of the current position of the stabilizer. Therefore, multiple MCAS commands resulted in a significant horizontal stabilizer mistrim condition, which the flightcrew could not counter using only elevator control. In the new design, Boeing included flight-control law changes that limit the magnitude of any MCAS command to move the horizontal stabilizer, so that the final horizontal stabilizer position (after the MCAS command) preserves the flightcrew's ability to control the airplane pitch by using only the control column.

13.4 Safety Issue #4 Flightcrew Recognition and Response

FDR data from both accidents show that the flightcrews were unable to effectively manage the stabilizer movement and multiple flight-deck effects that occurred as a result of the single AOA sensor failure. In the new design, Boeing revised eight non-normal flightcrew procedures and proposed additional training. The revised flightcrew procedures and pilot training provide the pilot with additional information to recognize erroneous stabilizer movement and the effects of AOA sensor failures.

13.5 Safety Issue #5 AOA DISAGREE Message

In the originally delivered configuration, the AOA DISAGREE alert message on the Primary Flight Display was not functional unless the airline chose the AOA indicator option. This alert message is intended to be standard on all 737MAX airplanes. In the new design,

Summary of the FAA's Review of the Boeing 737 MAX

Boeing revised the AOA DISAGREE implementation to maintain the original design intent to be standard on all 737 MAX aircraft. The FAA is requiring an additional software update that alerts the flightcrew to a disagreement between the two AOA sensors due to a sensor failure or calibration issues. The updated software implements an AOA DISAGREE alert message on all 737 MAX airplanes. While the lack of an AOA DISAGREE alert message is not an unsafe condition itself, the FAA is mandating this software update because the flightcrew procedures now rely on this alert message to guide flightcrew action.

13.6 Safety Issue #6 Other Possible Stabilizer Runaway Failures

The FAA and Boeing conducted a comprehensive review of the integrated SSA of the MCAS function. This review identified an extremely remote failure condition that required timely pilot intervention to ensure continued safe flight and landing. In the new design, Boeing has implemented a Cross-FCC Trim Monitor, which can effectively detect and shut down erroneous stabilizer commands from the FCCs. This makes continued safe flight and landing for this type of failure not dependent on pilot reaction time.

13.7 Safety Issue #7 Maintenance Procedures Related to MCAS

The KNKT final report for Flight JT610 shows several maintenance actions related to repair and installation of a replacement AOA sensor. *"The replacement AOA sensor that was installed on the accident aircraft had been mis-calibrated during an earlier repair. This mis-calibration was not detected during the repair. The investigation could not determine that the installation test of the AOA sensor was performed properly. The mis-calibration was not detected."* (Final KNKT.18.10.35.04 Aircraft Accident Investigation Report, page 215 linked [here](#)). The Collins Component Maintenance Manual for the AOA sensor has been revised to include a final check intended to prevent a repair shop instrumentation error. The KNKT investigation (Reference section 12.3) verified the existing Boeing AMM procedures for AOA sensor installation will correctly identify a mis-calibrated AOA sensor.

To ensure that each airplane's two AOA sensors are functioning properly upon return to service, operators will perform AOA Sensor System Tests on each airplane prior to its return to service. This test uses a fixture to position the AOA vane and verify that the reading provided by each AOA sensor is accurate.

13.8 Additional FAA Considerations

As a result of the FAA's review of the flight-control system of the 737 MAX, the Boeing-proposed design changes, the certification documentation (including the system safety assessment and system description document) and in consideration of systems that are indirectly related to MCAS, the FAA instructed Boeing to address the following:

- Mitigate single-point failures of the horizontal stabilizer trim system,

Summary of the FAA's Review of the Boeing 737 MAX

- Improve failure monitoring of the FCC, flight-control software and FCC signal inputs,
- Improve autopilot disengagement during low-speed and/or high-AOA operation,
- Reassess the manual trim and determine the system meets FAA requirements, and
- Reassess aircraft stall characteristics with STS/MCAS and Elevator Feel Shift inoperative and determine the aircraft meets FAA requirements.

The FAA determined that the 737 MAX design changes address the unsafe condition noted in the accident investigations and enhance the safety of the airplane's flight-control system architecture, operational procedures and maintenance procedures.

Appendix A: Emergency Order of Prohibition

**UNITED STATES DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION**

_____)
Operators of Boeing Company)
Model 737-8 and)
Boeing Company Model 737-9)
Airplanes)
_____)

EMERGENCY ORDER OF PROHIBITION

This Emergency Order of Prohibition is issued by the Federal Aviation Administration (FAA) pursuant to 49 U.S.C. § 40113(a) and § 46105(c). Effective immediately, this Order prohibits the operation of Boeing Company Model 737-8 and Boeing Company Model 737-9 airplanes by U.S. certificated operators. This Order also prohibits the operation of Boeing Company Model 737-8 and Boeing Company Model 737-9 series airplanes in the territory of the United States. Airplanes covered by this Order, if in flight at the time this Order is issued, may proceed to and complete their soonest planned landing, but may not again takeoff.

AUTHORITY

The FAA Administrator promotes the safe flight of civil aircraft by, among other things, prescribing minimum standards for practices, methods, and procedures the Administrator finds necessary for safety in air commerce. 49 U.S.C. § 44701(a)(5). The FAA Administrator is authorized to take necessary and appropriate actions to carry out his aviation safety duties and powers under part A (“Air Commerce and Safety”) of subtitle VII of Title 49 of the United States Code, including conducting investigations, issuing orders, and prescribing regulations, standards, and procedures. 49 U.S.C. § 40113(a). When the Administrator determines that an emergency exists related to safety in air commerce and requires immediate action, the

Administrator may issue immediately effective orders to meet the emergency. 49 U.S.C. § 46105(c).

SCOPE AND EFFECT

This Order applies to all persons operating the Boeing Company Model 737-8 and Boeing Company Model 737-9 airplanes in the territory of the United States, and to U.S. certificated operators conducting flights with Boeing Company Model 737-8 and Boeing Company Model 737-9 airplanes. These airplanes are hereinafter referred to as the Boeing 737 MAX series airplanes.

This Order is effective immediately. This Order prohibits the operation of Boeing 737 MAX series airplanes by U.S. certificated operators. This Order also prohibits the operation of Boeing 737 MAX series airplanes in the territory of the United States. Boeing 737 MAX series airplanes covered by this Order, if in flight at the time this Order is issued, may proceed to and complete their soonest planned landing, but may not again takeoff. Special flight permits may be issued in accordance with 14 C.F.R. § 21.197 and § 21.199, including to allow non-passenger carrying flights, as needed, for purposes of flight to a base for storage, production flight testing, repairs, alterations, or maintenance. Experimental airworthiness certificates may be issued in accordance with 14 C.F.R § 21.191 to support certification of design changes.

This Order remains in effect until the issuance of an applicable FAA order rescinding or modifying this Order. The Administrator will rescind or modify this Order, as appropriate, if the Administrator determines that the prohibitions prescribed herein are no longer necessary to address an emergency related to safety in air commerce.

BASIS FOR ORDER

Based on the initial investigations and the reliable and credible evidence presently available, the Acting Administrator finds that:

1. On October 29, 2018, a Boeing Company Model 737-8 operated by Lion Air as flight JT610 crashed after taking off from Soekarno-Hatta Airport in Jakarta, Indonesia. Flight JT610 departed from Jakarta with an intended destination of Pangkal Pinang, Indonesia. It departed Jakarta at 6:20 a.m. (local time), and crashed into the Java Sea approximately 13 minutes later. One hundred and eighty-four passengers and five crewmembers were on board. There were no survivors. An Indonesian-led investigation into the cause of this accident is ongoing, supported by the National Transportation Safety Board (NTSB), FAA, and Boeing.

2. On March 10, 2019, Ethiopian Airlines flight ET302, also a Boeing Company Model 737-8, crashed at 8:44 a.m. (local time), six minutes after takeoff. The flight departed from Bole International Airport in Addis Ababa, Ethiopia with an intended destination of Nairobi, Kenya. The accident site is near Bishoftu, Ethiopia. One hundred and forty-nine passengers and eight crewmembers were on board. None survived. An Ethiopian-led investigation into the cause of this accident is ongoing, supported by the NTSB, FAA, and Boeing.

3. The Boeing Company Model 737-8 and the Boeing Company Model 737-9 comprise the Boeing 737 MAX series, sharing nearly identical design features. The Boeing 737 MAX series airplanes are narrow-body airplanes with two high-bypass turbofan engines. The Boeing 737 MAX series airplanes are used for passenger carrying operations and are equipped with new CFM LEAP-1B engines and larger cockpit displays.

Under 49 U.S.C. § 46105(c), the Acting Administrator has determined that an emergency exists related to safety in air commerce. On March 13, 2019, the investigation of the ET302

crash developed new information from the wreckage concerning the aircraft's configuration just after takeoff that, taken together with newly refined data from satellite-based tracking of the aircraft's flight path, indicates some similarities between the ET302 and JT610 accidents that warrant further investigation of the possibility of a shared cause for the two incidents that needs to be better understood and addressed. Accordingly, the Acting Administrator is ordering all Boeing 737 MAX airplanes to be grounded pending further investigation.

This Order is effective immediately. While this Order remains in effect, the FAA intends to initiate a proceeding, as appropriate, to address the factors that contributed to the two previously discussed accidents involving Boeing 737 MAX series airplanes.

CONSEQUENCES OF FAILURE TO COMPLY WITH THIS ORDER

Any person who fails to comply with this Order is subject to a civil penalty for each flight found not to comply. Small business concerns and individuals (other than persons serving as an airman) are subject to a civil penalty of up to \$13,333 per flight. *See* 49 U.S.C. § 46301(a)(5)(A)(ii), 14 CFR 13.301. A person serving as an airman on a flight operated in violation of this Order is subject to a civil penalty of up to \$1,466 per flight or a certificate action, up to and including revocation. *See* 49 U.S.C. §§ 46301(a)(1)(B) and 44709(b)(1)(A), 14 CFR 13.301. An air carrier violating this Order is subject to certificate action, up to and including revocation. *See id.* Any person failing to comply with this Order may be subject to a cease and desist order or a civil action in a United States district court to ensure compliance. *See* 49 U.S.C. §§ 44103(a) and 46106.

RIGHT OF REVIEW

Pursuant to 49 U.S.C. § 46110(a), a person with a substantial interest in this Order "may apply for review of the order by filing a petition for review in the United States Court of Appeals

for the District of Columbia Circuit or in the court of appeals of the United States for the circuit in which the person resides or has its principal place of business.” The petition must be filed within 60 days after the date of this Order. 49 U.S.C. § 46110(a).

EMERGENCY CONTACT OFFICIAL

Direct any questions concerning this Emergency Order of Prohibition, to John Piccola, Federal Aviation Administration, Aircraft Certification Service, System Oversight Division, AIR-800, 2200 South 216th Street, Des Moines, WA 98198 (Email: john.piccola@faa.gov; Tel: 206-231-3595).

Dated: March 13, 2019



Daniel K. Elwell
Acting Administrator
Federal Aviation Administration

Appendix B: Continued Operational Safety Process Details

Initial Report

The FAA can receive reports of malfunctions and defects from any source. Typically, the agency receives voluntary information from several avenues, such as accident reports, airlines and defect reporting. U.S. aircraft companies are required to report to the FAA all malfunctions and defects that meet regulatory criteria in 14 CFR 21.3.

Subject Matter Expert Assessment

Based on the type of problem reported, AIR assigns the report to subject matter experts who have knowledge in the technical disciplines associated with the reported condition. These experts perform a qualitative assessment to determine the urgency of action required. This assessment establishes a critical decision point in their process. Subject matter experts engage in a thorough process that includes research into the possible causes, exchanges of information with the aircraft's designers and review of historical information. The FAA includes this assessment in the development of an AD, which is the tool for requiring mandatory corrective actions.

Risk Assessment

FAA specialists identify potential outcomes for the safety issue under review for risk analysis. When appropriate the agency uses product-specific risk analysis methods to calculate the quantitative probability, severity and risk for each outcome to determine the total uncorrected fleet risk and uncorrected individual aircraft risk. If these quantitative risk assessments values exceed FAA risk guidelines, the agency calculates timelines for corrective action to lower the risk to below the FAA risk guidelines.

Corrective Action Review Board (CARB)

Once a risk assessment is completed, the FAA convenes a CARB in which FAA specialists present their recommended actions, along with their risk analysis, causal analysis and quantitative evaluation of the risk reduction of corrective actions for concurrence. The goal of the CARB is to improve safety through better decision making by:

- Improving robustness of decision making through a forum in which a board of subject matter experts make key safety decisions.
- Providing for cross-functional review, allowing subject matter experts to raise concerns and contribute knowledge about a safety issue and proposed corrective action plan.
- Facilitating real-time, open exchange of safety issues across the key lifecycle disciplines.

Summary of the FAA's Review of the Boeing 737 MAX

- Providing a forum for the review of the preliminary risk analysis, risk analysis, causal analysis and corrective action(s) for a product type, leading to acceptance, rejection or revision of the proposed corrective action.
- Increasing knowledge and experience of the aviation community.

Manufacturer Corrective Action

Manufacturers typically propose corrective actions when the manufacturer or FAA identifies safety concerns. Proposals can range from initial interim mitigation to extensive final correction and terminating action. FAA specialists evaluate each proposed corrective action for its appropriateness and timeliness to mitigate the safety risk.

Issue Airworthiness Directive (AD)

After the CARB makes its safety determination that requires corrective action(s), the FAA issues an AD. An AD is a legally enforceable rule that applies to certain products (i.e., aircraft, aircraft engines, propellers, or appliances). Per 14 CFR § 39.5, the FAA issues an AD when (1) an unsafe condition exists in the product and (2), the condition is likely to exist or develop in other products of the same type design.

Appendix C: Emergency Airworthiness Directive



**FAA
Aviation Safety**

EMERGENCY AIRWORTHINESS DIRECTIVE

www.faa.gov/aircraft/safety/alerts/

DATE: November 7, 2018
AD #: 2018-23-51

Emergency Airworthiness Directive (AD) 2018-23-51 is sent to owners and operators of The Boeing Company Model 737-8 and -9 airplanes.

Background

This emergency AD was prompted by analysis performed by the manufacturer showing that if an erroneously high single angle of attack (AOA) sensor input is received by the flight control system, there is a potential for repeated nose-down trim commands of the horizontal stabilizer. This condition, if not addressed, could cause the flight crew to have difficulty controlling the airplane, and lead to excessive nose-down attitude, significant altitude loss, and possible impact with terrain.

FAA's Determination

We are issuing this AD because we evaluated all the relevant information and determined the unsafe condition described previously is likely to exist or develop in other products of the same type design. Due to the need to correct an urgent safety of flight situation, good cause exists to make this AD effective in less than 30 days.

AD Requirements

This AD requires revising certificate limitations and operating procedures of the airplane flight manual (AFM) to provide the flight crew with runaway horizontal stabilizer trim procedures to follow under certain conditions.

Interim Action

We consider this AD interim action. If final action is later identified, we might consider further rulemaking then.

Authority for this Rulemaking

Title 49 of the United States Code specifies the FAA's authority to issue rules on aviation safety. Subtitle I, Section 106, describes the authority of the FAA Administrator. Subtitle VII, Aviation Programs, describes in more detail the scope of the Agency's authority.

We are issuing this rulemaking under the authority described in Subtitle VII, Part A, Subpart III, Section 44701, "General requirements." Under that section, Congress charges the FAA with promoting safe flight of civil aircraft in air commerce by prescribing regulations for practices, methods, and procedures the Administrator finds necessary for safety in air commerce. This regulation is within the scope of that authority because it addresses an unsafe condition that is likely to exist or develop on products identified in this rulemaking action.

This AD is issued in accordance with authority delegated by the Executive Director, Aircraft Certification Service, as authorized by FAA Order 8000.51C. In accordance with that order, issuance of ADs is normally a function of the Compliance and Airworthiness Division, but during this transition period, the Executive Director has delegated the authority to issue ADs applicable to transport category airplanes and associated appliances to the Director of the System Oversight Division.

Presentation of the Actual AD

We are issuing this AD under 49 U.S.C. Section 44701 according to the authority delegated to me by the Administrator.

2018-23-51 The Boeing Company: Product Identifier 2018-NM-151-AD.

(a) Effective Date

This Emergency AD is effective upon receipt.

(b) Affected ADs

None.

(c) Applicability

This AD applies to all The Boeing Company Model 737-8 and -9 airplanes, certificated in any category.

(d) Subject

Air Transport Association (ATA) of America Code 27, Flight controls.

(e) Unsafe Condition

This AD was prompted by analysis performed by the manufacturer showing that if an erroneously high single angle of attack (AOA) sensor input is received by the flight control system, there is a potential for repeated nose-down trim commands of the horizontal stabilizer. We are issuing this AD to address this potential resulting nose-down trim, which could cause the flight crew to have difficulty controlling the airplane, and lead to excessive nose-down attitude, significant altitude loss, and possible impact with terrain.

(f) Compliance

Comply with this AD within the compliance times specified, unless already done.

(g) Revision of Airplane Flight Manual (AFM): Certificate Limitations

Within 3 days after receipt of this AD, revise the Certificate Limitations chapter of the applicable AFM to include the information in figure 1 to paragraph (g) of this AD.

Figure 1 to paragraph (g) of this AD – *Certificate Limitations*

Required by AD 2018-23-51

Runaway Stabilizer

In the event of an uncommanded horizontal stabilizer trim movement, combined with any of the following potential effects or indications resulting from an erroneous Angle of Attack (AOA) input, the flight crew must comply with the Runaway Stabilizer procedure in the Operating Procedures chapter of this manual:

- Continuous or intermittent stick shaker on the affected side only.
- Minimum speed bar (red and black) on the affected side only.
- Increasing nose down control forces.
- IAS DISAGREE alert.
- ALT DISAGREE alert.
- AOA DISAGREE alert (if the option is installed).
- FEEL DIFF PRESS light.
- Autopilot may disengage.
- Inability to engage autopilot.

(h) AFM Revision: Operating Procedures

Within 3 days after receipt of this AD, revise the Operating Procedures chapter of the applicable AFM to include the information in figure 2 to paragraph (h) of this AD.

Figure 2 to paragraph (h) of this AD – Operating Procedures

Required by AD 2018-23-51

Runaway Stabilizer

Disengage autopilot and control airplane pitch attitude with control column and main electric trim as required. If relaxing the column causes the trim to move, set stabilizer trim switches to CUTOOUT. If runaway continues, hold the stabilizer trim wheel against rotation and trim the airplane manually.

Note: The 737-8/-9 uses a Flight Control Computer command of pitch trim to improve longitudinal handling characteristics. In the event of erroneous Angle of Attack (AOA) input, the pitch trim system can trim the stabilizer nose down in increments lasting up to 10 seconds.

In the event an uncommanded nose down stabilizer trim is experienced on the 737-8/-9, in conjunction with one or more of the indications or effects listed below, do the existing AFM Runaway Stabilizer procedure above, ensuring that the STAB TRIM CUTOOUT switches are set to CUTOOUT and stay in the CUTOOUT position for the remainder of the flight.

An erroneous AOA input can cause some or all of the following indications and effects:

- Continuous or intermittent stick shaker on the affected side only.
- Minimum speed bar (red and black) on the affected side only.
- Increasing nose down control forces.
- IAS DISAGREE alert.
- ALT DISAGREE alert.
- AOA DISAGREE alert (if the option is installed).
- FEEL DIFF PRESS light.
- Autopilot may disengage.
- Inability to engage autopilot.

Initially, higher control forces may be needed to overcome any stabilizer nose down trim already applied. Electric stabilizer trim can be used to neutralize control column pitch forces before moving the STAB TRIM CUTOOUT switches to CUTOOUT. Manual stabilizer trim can be used before and after the STAB TRIM CUTOOUT switches are moved to CUTOOUT.

(i) Alternative Methods of Compliance (AMOCs)

(1) The Manager, Seattle ACO Branch, FAA, has the authority to approve AMOCs for this AD, if requested using the procedures found in 14 CFR 39.19. In accordance with 14 CFR 39.19, send your request to your principal inspector or local Flight Standards District Office, as appropriate. If sending information directly to the manager of the certification office, send it to the attention of the person identified in paragraph (j) of this AD. Information may be emailed to: 9-ANM-Seattle-ACO-AMOC-Requests@faa.gov.

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(2) Before using any approved AMOC, notify your appropriate principal inspector, or lacking a principal inspector, the manager of the local flight standards district office/certificate holding district office.

(j) Related Information

For further information about this AD, contact Douglas Tsuji, Senior Aerospace Engineer, Systems and Equipment Section, FAA, Seattle ACO Branch, 2200 South 216th St., Des Moines, WA 98198; phone and fax: 206-231-3548; email: Douglas.Tsuji@faa.gov.

Issued in Des Moines, Washington, on November 7, 2018.

Original signed by
Chris Spangenberg,
Acting Director,
System Oversight Division,
Aircraft Certification Service.

Appendix D: Continued Airworthiness Notifications to the International Community

Continued Airworthiness Notification to the International Community

To: Civil Aviation Authorities

Date: November 6, 2018

From: Federal Aviation Administration
Aircraft Certification Service
System Oversight Division, AIR-800
2200 South 216th Street
Des Moines, WA 98198

Subject: This message is to advise you of the FAA's ongoing activities related to the accident of Lion Air Flight 610 on October 29, 2018.

Situation description: On October 29, 2018, a Boeing Model 737-8 airplane crashed after taking off from Soekarno-Hatta Airport in Jakarta, Indonesia. The airplane, operated by Lion Air, an Indonesian operator, departed Jakarta for Pangkai Pinang, Indonesia, and crashed into the Java Sea about 13 minutes later. Of the 184 passengers and 5 crew members on board, there were no survivors.

Aircraft/engine make, model, and series: Boeing 737-8 and -9 series airplanes

U.S.-registered fleet: 45 airplanes; **Worldwide fleet:** 246 airplanes

Operators: 44 operators worldwide: Aerolineas Argentinas, Aeromexico, Air Canada, Air China, American Airlines, Britannia Airways AB, China Eastern Airlines, China Southern Airlines, COPA Airlines, Corendon Airlines, Ethiopian Airlines, flydubai, Garuda Indonesia, GOL Transportes Aereos Ltda, Hainan Airlines, Icelandair, Jet Airways, Jet Aviation Business Jets, JSC Aircompany SCAT, Kunming Airlines, Lion Air, LOT Polish Airlines, Mauritania Airlines, Meridiana (Italy), Norwegian Air Norway, Norwegian Air Shuttle AS, Norwegian Long Haul AS, Okay Airways Company Limited, Oman Air, Shandong Airlines, Shanghai Airlines, Shenzhen Airlines, SilkAir, Southwest Airlines, SpiceJet, Sunwing Airlines Inc., Thai Lion, Travel Service, TUI Airlines Belgium, Turkish Airlines (THY), United Airlines, WestJet, and Xiamen Airlines.

Ongoing activities: The FAA and the National Transportation Safety Board (NTSB) have been supporting the Indonesian National Transportation Safety Committee (NTSC) in investigating this accident. The accident airplane appears to have experienced anomalies in the angle of attack, airspeed, and altitude indications.

Boeing has released a Flight Crew Operations Manual Bulletin (OMB) to provide procedures for a failure condition resulting from erroneous angle of attack (AOA), during manual flight only.

The FAA is considering issuance of an airworthiness directive to require those Flight Crew OMB procedures.

FAA contact: Jeffrey E. Duven, Director, System Oversight Division
Telephone and Fax: (206) 231-3200

Continued Airworthiness Notification to the International Community

To: Civil Aviation Authorities

Date: March 13, 2019

From: Federal Aviation Administration (FAA)
Aircraft Certification Service
System Oversight Division, AIR-800
2200 South 216th Street Des Moines, WA 98198

Subject: This message provides updated information regarding FAA continued operations safety activity related to the Boeing Model 737-8 and 737-9 (737 MAX) fleet.

Situation description: On March 11, 2019, the FAA issued a CANIC discussing the status of the Ethiopian Airlines Flight ET302, Boeing Model 737-8 accident investigation. At that time, we indicated we are closely examining all data associated with the accident.

On March 13, 2019, the investigation of the Flight ET302 accident developed new information from the wreckage concerning the aircraft's configuration just after takeoff that, taken together with newly refined data from satellite-based tracking of the aircraft's flight path, indicates some similarities between the Flight ET302 and Lion Air Flight JT610 accidents. This new information warrants further investigation of the possibility of a shared cause for the two incidents that needs to be better understood and addressed.

Therefore, the FAA issued an Emergency Order of Prohibition, which prohibits the operation of Boeing Company Model 737-8 and Boeing Company Model 737-9 airplanes by U.S. certificated operators or in U.S. territory.

We continue to pursue and analyze any information discovered during the investigation as it becomes available. The cockpit voice recorder (CVR) and flight data recorder (FDR) have been found, but the data has not been processed at this time.

Aircraft/engine make, model, and series: The Boeing Company Model 737-8 and 737-9 airplanes (737 MAX)

U.S.-registered fleet: 74 airplanes as of March 11, 2019

Worldwide fleet: 387 airplanes as of March 11, 2019

Operators: As of March 11, 2019; 59 operators worldwide: 9 Air, Aerolineas Argentinas, Aeromexico, Air Canada, Air China, Air Fiji, AIR ITALY S.P.A., American Airlines, Arkefly, Britannia Airways AB, Cayman Airways, China Eastern Airlines, China Southern Airlines, Comair, COPA Airlines, Corendon Airlines, Eastar Jet, Enter Air Sp. Z O.O., Ethiopian Airlines, Fertitta Enterprises, Inc., flydubai, Fuzhou Airlines Co., Ltd, Garuda Indonesia, Gol Linhas Aereas S.A., Hainan Airlines, Icelandair, Jet Airways, Jet Aviation Business Jets, JSC Aircompany SCAT, Kunming Airlines, Lion Air, Globus Airlines, LOT Polish Airlines, Lucky Air, Mauritania Airlines, Mongolian Airlines MIAT, Norwegian Air International Lt, Norwegian Air Norway, Norwegian Air Shuttle AS, Norwegian Air Sweden, Okay Airways Company Limited, Oman Air, Qatar Airways, Royal Air Maroc, Shandong Airlines, Shanghai Airlines, Shenzhen Airlines, SilkAir, Smartwings, Southwest Airlines, SpiceJet, Sunwing Airlines Inc., Thai Lion, TUI Airlines Belgium, TUI Airways, Turkish Airlines (THY), United Airlines, WestJet, Xiamen Airlines

FAA Contact: Jeffrey E. Duven, Director, System Oversight Division
Telephone and Fax: (206) 231-3200

Continued Airworthiness Notification to the International Community

To: Civil Aviation Authorities

Date: March 20, 2019

From: Federal Aviation Administration (FAA)
Aircraft Certification Service
System Oversight Division, AIR-800
2200 South 216th Street
Des Moines, WA 98198

Subject: This message provides updated information regarding the FAA's continued operational safety activities related to the Boeing Model 737-8 and 737-9 (737 MAX) fleet.

Situation description: On March 13, 2019, the investigations of the Lion Air Flight JT610 accident and the Ethiopian Airlines Flight ET302 accident, both involving Boeing Model 737-8 airplanes, developed new information indicating some similarities between the two accidents. Therefore, the FAA issued an Emergency Order of Prohibition that prohibits the operation of Boeing Model 737-8 and 737-9 airplanes by U.S.-certificated operators or in U.S. territory. The Order remains in effect.

In an earlier CANIC, issued on March 11, 2019, the FAA provided information regarding Boeing's development of flight control system changes to address the Lion Air accident. The FAA is aware that Boeing is developing a Service Bulletin that would specify the installation of new flight control computer operational program software. Boeing has also developed flightcrew training related to this software. The FAA's ongoing review of this software installation and training is an agency priority, as will be the roll-out of any software, training, or other measures to operators of the 737 MAX.

The information provided through this CANIC is based on the information currently available to the FAA. The FAA will also continue to analyze any information discovered during the investigation of Flight ET302 as it becomes available to the agency. The cockpit voice recorder (CVR) and flight data recorder (FDR) information have been downloaded from the units and are in possession of the Ethiopian authorities. Understanding the circumstances that contributed to this accident is critical in developing further actions and returning aircraft to service.

Aircraft/engine make, model, and series: The Boeing Company Model 737-8 and 737-9 airplanes (737 MAX)

U.S.-registered fleet: 74 airplanes as of March 11, 2019

Worldwide fleet: 387 airplanes as of March 11, 2019

Operators: As of March 11, 2019; 59 operators worldwide: 9 Air, Aerolineas Argentinas, Aeromexico, Air Canada, Air China, Air Fiji, AIR ITALY S.P.A., American Airlines, Arkefly, Britannia Airways AB, Cayman Airways, China Eastern Airlines, China Southern Airlines, Comair, COPA Airlines, Corendon Airlines, Eastar Jet, Enter Air Sp. Z O.O., Ethiopian Airlines, Fertitta Enterprises, Inc., flydubai, Fuzhou Airlines Co., Ltd, Garuda Indonesia, Gol Linhas Aereas S.A., Hainan Airlines, Icelandair, Jet Airways, Jet Aviation Business Jets, JSC Aircompany SCAT, Kunming Airlines, Lion Air, Globus Airlines, LOT Polish Airlines,

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Lucky Air, Mauritania Airlines, Mongolian Airlines MIAT, Norwegian Air International Lt, Norwegian Air Norway, Norwegian Air Shuttle AS, Norwegian Air Sweden, Okay Airways Company Limited, Oman Air, Qatar Airways, Royal Air Maroc, Shandong Airlines, Shanghai Airlines, Shenzhen Airlines, SilkAir, Smartwings, Southwest Airlines, SpiceJet, Sunwing Airlines Inc., Thai Lion, TUI Airlines Belgium, TUI Airways, Turkish Airlines (THY), United Airlines, WestJet, Xiamen Airlines

FAA Contact: Jeffrey E. Duven, Director, System Oversight Division
Telephone and Fax: (206) 231-3200

Appendix E: Acronyms

AC	Advisory Circular
AD	Airworthiness Directive
ADIRS	Air Data Inertial Reference System
ADIRU	Air Data Inertial Reference Unit
ADRC	Additional Design Requirements and Conditions
ADS-B	Automatic Dependent Surveillance-broadcast
AEG (AED)	Aircraft Evaluation Group (now Aircraft Evaluation Division)
AFM	Airplane Flight Manual
AFX	FAA Flight Standards Service
AIR	FAA Aircraft Certification Service
AMM	Airplane Maintenance Manual
AMO	Approved Maintenance Organization
ANAC	Civil Aviation National Agency of Brazil
ANU	Airplane Nose-up
AOA	Angle of Attack
ALT HLD	Altitude Hold
ARP	Aerospace Recommended Practice
ATA	Airline Transport Association
ATC	Air Traffic Control
AVS	FAA Aviation Safety
BASOO	Boeing Aviation Safety Oversight Office
BITE	Built-in-test Equipment
BOV	Bias Out of View
CAA	Civil Aviation Authority
CANIC	Continued Airworthiness Notification to the International Community
CARB	Continued Airworthiness Review Board
CDU	Cockpit Display Unit
CFR	Code of Federal Regulations

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CMM	Component Maintenance Manual
CMR	Certification Maintenance Requirement
COS	Continued Operational Safety
CPU	Central Processing Unit
CRI	Certification Review Item (EASA)
CS	Compliance Standard (EASA)
CWS	Control Wheel Steering
DA	Development (or Design) Assurance
DFCS	Digital Flight Control System
DFDR	Digital Flight Data Recorder
DPC	Display Processing Computer
EASA	European-Union Aviation Safety Agency
EDFCS	Enhanced Digital Flight Control System
ETOPS	Extended Operations
E-UM	Engineering Unit Member
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCC	Flight Control Computer
FCTM	Flightcrew Training Manual
FDR	Flight Data Recorder
FFS	Full Flight Simulator
FLT CONT	Flight Control
FO	First Officer
FSB	Flight Standardization Board
GPWS	Ground Proximity Warning System
IAS	Indicated Airspeed
ICA	Instructions for Continued Airworthiness
ICAO	International Civil Aviation Organization
IFIM	Interactive Fault Isolation Manual
IP	Issue Paper
JATR	Joint Authorities Technical Review

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JOEB	Joint Operations Evaluation Board
KNKT	Komite Nasional Keselamatan Transportasi (Indonesia's National Transportation Safety Committee)
LVL CHG	Level Change
MCAI	Mandatory Continued Airworthiness Information
MCAS	Maneuvering Characteristics Augmentation System
MMEL	Master Minimum Equipment List
MPD	Maintenance Planning Document
MRBR	Maintenance Review Board Report
MSAD	Monitor Safety/Analyze Data
MSI	Maintenance Significant Item
MVS	Middle Value Select
NASA	National Aeronautics and Space Administration
NNC	Non Normal Checklist
NTSB	National Transportation Safety Board
ODA	Organization Designation Authorization
PFD	Primary Flight Display
QRH	Quick Reference Handbook
RTS	Return To Service
SB	Service Bulletin
SDS	System Description Sections
SMS	Safety Management System
SSA	System Safety Analysis
STM	Stabilizer Trim Motor
STS	Speed Trim System
TAB	Technical Advisory Board
TC	Type Certificate
TCCA	Transport Canada
TCDS	Type Certificate Data Sheet
U.S.	United States
VNAV	Vertical Navigation