



# FAA Has Completed 737 MAX Return to Service Efforts, but Opportunities Exist To Improve the Agency's Risk Assessments and Certification Processes



## FAA Has Completed 737 MAX Return to Service Efforts, but Opportunities Exist To Improve the Agency's Risk Assessments and Certification Processes

*Requested by the Secretary of Transportation; the Chairmen of the House Committee on Transportation and Infrastructure and its Subcommittee on Aviation; the Chairman and Ranking Member of the Senate Committee on Appropriations, Subcommittee on Transportation, Housing and Urban Development, and Related Agencies; and Senator Richard Blumenthal*

Federal Aviation Administration | AV2023025 | April 26, 2023

### What We Looked At

The Federal Aviation Administration (FAA) has historically maintained an excellent safety record. However, two fatal accidents in 2018 and 2019 involving the Boeing 737 MAX 8 raised concerns about FAA's oversight and certification of civilian aircraft manufactured and operated in the United States. At the request of Secretary of Transportation Elaine L. Chao and several members of Congress, our office has undertaken a series of reviews related to FAA's certification of the MAX and its safety oversight. This is the third report in that series. It focuses on FAA's risk assessments following the accidents, as well as the recertification and return to service efforts for the MAX. Accordingly, our audit objective was to evaluate FAA's processes and procedures for grounding aircraft and implementing corrective actions, including for the MAX 8. Specifically, we evaluated FAA's risk assessment processes following the accidents, and the Agency's process for returning the airplane to service.

### What We Found

FAA's steps following the accidents were in line with its overall post-event risk assessment processes; however, we identified some areas that may impact the Agency's response in the future. First, FAA's processes, by design, allow for significant flexibility in order to factor in the judgment of engineers. Second, FAA has not updated the underlying order and related guidance for its post-event risk assessment processes in over a decade. Third, the Agency lacks quantifiable human factors data, such as pilot reactions to non-normal situations. Finally, FAA's engineers are not all following or receiving the same guidance or training. As a result, FAA may not be able to ensure it consistently follows the most effective risk assessment processes following a safety event.

FAA completed the recertification of the 737 MAX on November 18, 2020. During the recertification process, the Agency retained regulatory compliance findings for the design changes instead of delegating them to Boeing's Organization Designation Authorization (ODA) program. Numerous complex issues from multiple safety reviews prompted FAA to require Boeing to submit a document demonstrating the effects of Boeing's proposed changes on the speed trim system and how those changes affected the safe operation of the MAX. While FAA is incorporating many of the lessons learned from the MAX recertification efforts for future projects, there are still improvements and procedures currently being codified by the Agency.

### Our Recommendations

We made seven recommendations to improve FAA's processes for risk assessment and determination of corrective actions. FAA concurred with all our recommendations and provided appropriate actions and planned completion dates.

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## Memorandum

Date: April 26, 2023

Subject: ACTION: FAA Has Completed 737 MAX Return to Service Efforts, but Opportunities Exist To Improve the Agency's Risk Assessments and Certification Processes | Report No. AV2023025

From: Nelda Z. Smith   
Assistant Inspector General for Aviation Audits

To: Federal Aviation Administrator

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Upholding safety is a primary mission of the Federal Aviation Administration (FAA). This includes overseeing the certification and safety of all civilian aircraft manufactured and operated in the United States. FAA has historically maintained an excellent safety record. However, two fatal accidents in 2018 and 2019 and the subsequent grounding of Boeing 737 MAX 8<sup>1</sup> aircraft raised questions and concerns about FAA's certification processes, monitoring of in-service fleets, and oversight of aircraft manufacturers.

Specifically, on October 29, 2018, Lion Air Flight 610 crashed into the Java Sea shortly after departing Soekarno-Hatt International Airport, Jakarta, resulting in 189 fatalities. Following that accident, FAA issued an emergency airworthiness directive (AD<sup>2</sup>) on November 7 that directed operators of the MAX to revise their airplane flight manuals. This AD was an interim action designed to mitigate risk until Boeing could develop and implement a software update that would correct design issues related to MCAS. However, just over 4 months after the first accident, on March 10, 2019, Ethiopian Airlines Flight 302 crashed shortly after departing Addis Ababa Bole International Airport, resulting in 157 fatalities, including 8 Americans. Both crashes involved the Boeing 737 MAX 8 aircraft model. On March 13, 2019, FAA grounded the entire 737 MAX 8 and 737 MAX 9<sup>3</sup> fleet, following the grounding of the airplane by several international authorities in the preceding days.<sup>4</sup> Twenty months later, on November 18, 2020, after Boeing

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<sup>1</sup> The official model number of the Boeing 737 MAX 8 is the 737-8.

<sup>2</sup> Legally enforceable rules issued by FAA that apply to aircraft, aircraft engines, propellers, and appliances.

<sup>3</sup> The official model number of the Boeing 737 MAX 9 is the 737-9.

<sup>4</sup> For example, the Civil Aviation Authority of China suspended commercial operation of the MAX on March 11, 2019, and the European Union Aviation Safety Agency suspended operation of the MAX on March 12, 2019.

made FAA-mandated design and operational changes, the Agency rescinded the grounding order and issued a final airworthiness directive, thus allowing the 737 MAX to return to service.

At the request of Secretary Elaine L. Chao and members of Congress,<sup>5</sup> our office has undertaken a series of reviews<sup>6</sup> related to FAA's certification of the 737 MAX 8 and its safety oversight, including the Agency's oversight of Boeing's Organization Designation Authorization (ODA) program.<sup>7</sup> This is the third report in that series, and it focuses on FAA's risk assessments following the two accidents, as well as the recertification and return to service efforts for the Boeing MAX. Accordingly, our audit objective was to evaluate FAA's processes and procedures for grounding aircraft and implementing corrective actions, including for the Boeing 737 MAX 8. Specifically, we evaluated FAA's risk assessment processes following the Boeing 737 MAX 8 crashes in October 2018 and March 2019, and the Agency's process for returning the airplane to service.

We conducted this audit in accordance with generally accepted Government auditing standards. Exhibit A details our scope and methodology. Exhibit B lists the organizations we visited or contacted, and exhibit C lists the acronyms used in this report.

We appreciate the courtesies and cooperation of Department of Transportation (DOT) representatives during this audit. If you have any questions concerning this report, please contact me or Marshall Jackson, Program Director.

cc: The Secretary  
DOT Audit Liaison, M-1  
FAA Audit Liaison, AAE-100

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<sup>5</sup> On March 19, 2019, Secretary of Transportation Elaine L. Chao requested that we compile an objective and detailed factual history of the activities that resulted in the certification of the 737 MAX 8. We also received similar requests from the Chairmen of the House Committee on Transportation and Infrastructure and its Subcommittee on Aviation; the Chairman and Ranking Member of the Senate Committee on Appropriations, Subcommittee on Transportation, Housing and Urban Development, and Related Agencies; and Senator Richard Blumenthal.

<sup>6</sup> *Timeline of Activities Leading to the Certification of the Boeing 737 MAX 8 Aircraft and Actions Taken After the October 2018 Lion Air Accident* (OIG Report No. AV2020037), June 29, 2020, and *Weaknesses in FAA's Certification and Delegation Processes Hindered its Oversight of the 737 MAX 8* (OIG Report No. AV2021020) February 23, 2021. OIG reports are available on our website at [www.oig.dot.gov/](http://www.oig.dot.gov/).

<sup>7</sup> FAA created the ODA program in 2005 to standardize its oversight of organizational designees (e.g., aircraft manufacturers) that have been approved to perform certain functions on the Agency's behalf, such as determining compliance with aircraft certification regulations.

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## Background

The Boeing 737 MAX series<sup>8</sup> is the fourth-generation model of Boeing's 737 aircraft series, which FAA first certificated in 1967. The 737 MAX 8 received FAA certification as an amended type certificate<sup>9</sup> in March 2017. It included a function in the flight control software—the Maneuvering Characteristics Augmentation System (MCAS)—that Boeing used in a new way on the 737 MAX.<sup>10</sup> MCAS modifies aircraft handling characteristics in manual flight as an additional function of the existing aircraft speed trim system. This function is intended to compensate for changes in aerodynamics from the previous model caused by the MAX's larger engines and the placement of those engines on the wing.

Specifically, as originally designed, MCAS could command the airplane's horizontal stabilizer<sup>11</sup> to move without pilot input in certain, limited aircraft configurations<sup>12</sup> related to airspeed and the angle of the aircraft in the air—known as Angle-of-Attack.<sup>13</sup> Under certain failure conditions, MCAS could command the plane's nose down beyond the intended design limit during manual flight if not counteracted by the pilot. According to FAA, and both accident investigation reports,<sup>14</sup> MCAS was a significant contributing factor for both accidents. MCAS activated after receiving faulty data from one of the aircraft's two Angle-of-Attack sensors—external sensors that measure the angle of the aircraft in the air.

Following all reported potential operational events for transport category aircraft, FAA Aircraft Certification Offices (ACO) use the risk-based Continued Operational Safety process to determine if an unsafe condition exists in an aircraft fleet, and to develop corrective actions. For certain reported events and conditions, such as failure of a part during flight or the discovery of a regulatory noncompliance, FAA's Continued Operational Safety process assesses risk post-certification to ensure an acceptable level of safety in every seat on every flight. (See figure 1 for a general overview of the process.) Under the process, aircraft manufacturers

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<sup>8</sup> The 737 MAX series includes the 7, 8, 9, 10, and 8200. The MAX 7 and 10 have not yet been certified by FAA.

<sup>9</sup> An Amended Type Certificate (ATC) is issued by FAA when the holder of a type certificate receives FAA approval to modify an aircraft design from its original design. An ATC approves not only the modification but also how that modification affects the original design.

<sup>10</sup> While MCAS is included on some military versions of the Boeing 767 refueling tanker, the system has different features on that model.

<sup>11</sup> A control surface near the tail of the airplane that controls up and down movement of the airplane.

<sup>12</sup> These configurations include the plane being in manual flight (autopilot off) and the flaps being in an up position.

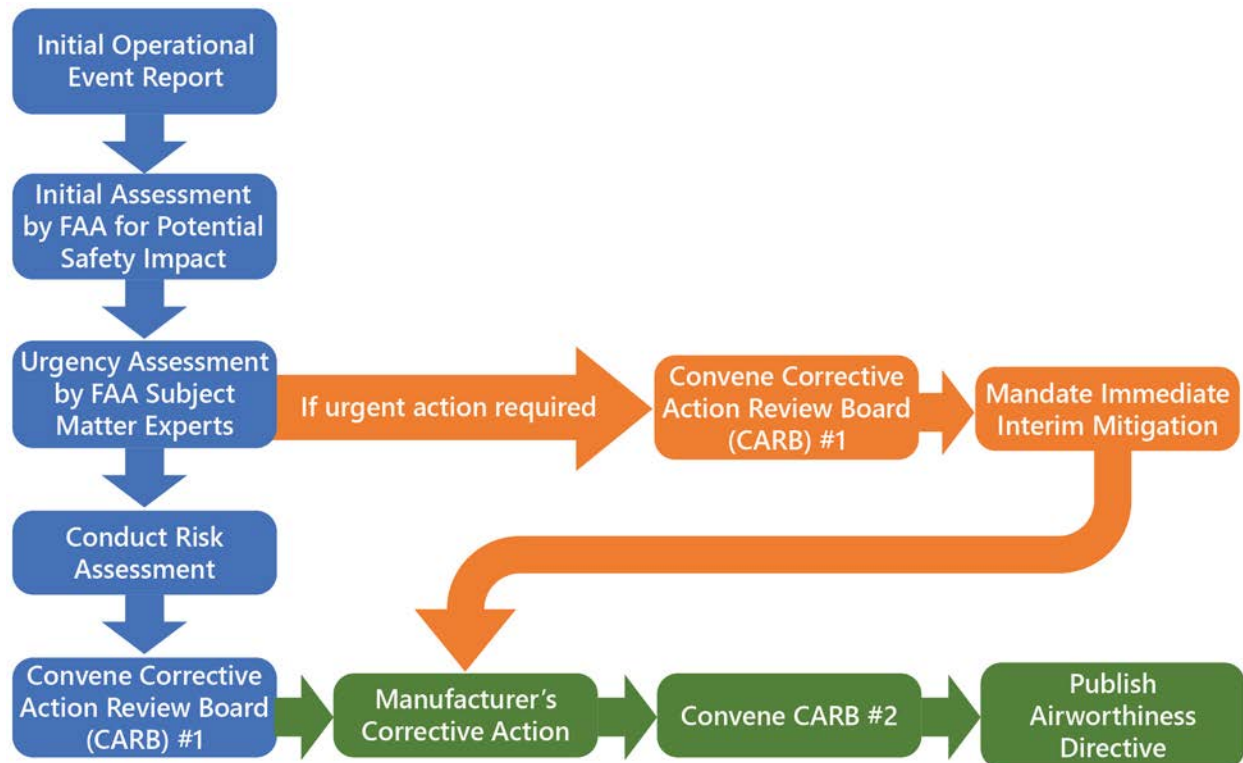
<sup>13</sup> Angle-of-Attack is the difference between the pitch angle (nose direction) of the airplane and the angle of the oncoming wind.

<sup>14</sup> Komite Nasional Keselamatan Transportasi Republic of Indonesia. KNKT.18.10.35.04. FINAL. 2019. Federal Democratic Republic of Ethiopia, Ministry of Transport and Logistics. Aircraft Accident Investigation Bureau. Report No AI-01/19. December 23, 2022.



report events to FAA, including failures, malfunctions, and defects. FAA filters the operational reports to determine potential safety events for further review and conducts an urgency assessment based on the reports to determine if immediate action is needed, such as an Emergency Airworthiness Directive (AD) or aircraft grounding. ACO engineers then conduct a quantitative risk analysis and compare the results with established guidelines to determine if action is recommended. The Corrective Action Review Board<sup>15</sup> (CARB) formally reviews the results to determine if there is an unsafe condition, urgency of action, and what action is required. Later, the CARB also reviews and approves the manufacturer's proposed corrective action(s) and determines the maximum time recommended to implement a fix, based on the risk analysis. Finally, FAA formally mandates the action by AD. FAA can require interim corrective actions to reduce risk while the final action is in development.

Figure 1. Key Steps<sup>16</sup> in the Continued Operational Safety Process



Source: OIG analysis of FAA's review of the Boeing 737 MAX Summary

<sup>15</sup> The CARB is a panel of FAA experts at an ACO. It includes a manager, the engineer or pilot presenting the issue, and at least three additional engineers. Additional FAA offices also participate, including the Aircraft Evaluation Division, Certificate Management Office, and/or Manufacturing Inspection District Office.

<sup>16</sup> Risk assessments are also conducted on urgent actions. In addition, the Continued Operational Safety steps are shown sequentially, but may be completed concurrently or out of sequence.

Fleet-wide groundings are rare events. Prior to the Boeing 737 MAX grounding, FAA's last return-to-service effort was in 2013 for the Boeing 787 that was grounded because of two significant lithium ion battery failures. FAA mandated modifications via an AD<sup>17</sup> to consider all potential causal factors of the two Boeing 787 battery failure events. Return-to-service efforts focus on identifying safety issues and contributing factors, collaborating with key civil aviation authorities around the world to ensure transparency, and working with subject matter experts external to FAA to validate the Agency's steps leading to final design approval for return to service. To fulfill these goals, the Agency issued an AD to address unsafe conditions and fulfill international obligations from the International Civil Aviation Organization (ICAO) Annex 8.<sup>18</sup>

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## Results in Brief

**FAA followed its established risk assessment processes following the Lion Air and Ethiopian Airlines accidents; however, limitations in these processes may impact responses to future events.**

FAA's steps following the Lion Air and Ethiopian Airlines accidents were in line with its overall post-event risk assessment processes; however, we identified some areas that may impact the Agency's response to future events. FAA has an established criteria and methodology for evaluating risks following a potential safety event, including determining whether an aircraft should be grounded. FAA followed these processes following the Lion Air MAX accident, including completing quantitative assessments, convening a technical board to evaluate corrective actions, and coming to an agreement with Boeing regarding a timeframe for implementing those corrective actions. Following the March 2019 Ethiopian Airlines accident, FAA began its quantitative risk assessment process but faced challenges in analyzing the limited initial data from the crash, which did not conclusively point to a safety flaw in the aircraft. The Agency waited until it received more detailed data before grounding the aircraft. FAA's actions aligned with its typical processes following events. Nevertheless, we identified some limitations in those processes that may impact the Agency's responses to future events. First, FAA's processes, by design, allow for significant flexibility in order to factor in the judgment of engineers. However, this judgment, even when expressed numerically, is not always informed by relevant, quantifiable data. Such engineering judgment formed the basis of FAA's decision to set a June 2019

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<sup>17</sup> Final AD 2013-08-12 was issued on April 26, 2013.

<sup>18</sup> "Summary of the FAA's Review of the Boeing 737 MAX," published on November, 18, 2020, served as the Agency's starting document to be used with the AD through ICAO for other civil aviation authorities around the world to determine airworthiness of the 737 MAX.



completion date for corrective action following the Lion Air accident. Second, FAA has not updated the underlying order and related guidance for its post-event risk assessment processes in over a decade, and do not include international data in some cases. Third, the Agency lacks quantifiable human factors data, such as pilot reactions to non-normal situations. Finally, FAA's engineers are not all following or receiving the same guidance or training. For example, due to a need for more specific guidance for assessing risk following transport aircraft safety events, FAA's Seattle ACO created its own supplemental guidance document—but this guidance is not required for all ACOs. As a result, FAA may not be able to ensure it consistently follows the most effective risk assessment processes following a safety event.

**FAA completed recertification, returned the 737 MAX to service, and is refining the certification process based on lessons learned.**

FAA completed the recertification of the 737 MAX on November 18, 2020. During the recertification process, the Agency retained regulatory compliance findings for the design changes instead of delegating them to Boeing's ODA. Over the course of the review, numerous complex issues from multiple safety reviews prompted FAA to require Boeing to submit a comprehensive integrated System Safety Assessment<sup>19</sup> for the speed trim system.<sup>20</sup> This document demonstrated the effects of Boeing's proposed changes on the speed trim system and how those changes affected the safe operation of the MAX. FAA also re-evaluated the training and handling differences between the 737 MAX and the 737 NG, the previous generation of aircraft before the MAX. FAA later agreed with Boeing's request to add full flight simulator training to the company's previously proposed pilot training. While FAA is incorporating many of the lessons learned from the MAX recertification efforts for future projects, there are still improvements and procedures currently being codified by the Agency.

We made seven recommendations to improve FAA's processes for risk assessment and determination of corrective actions.

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<sup>19</sup> An assessment of the process to identify and classify failure conditions and ensuing means for regulatory compliance.

<sup>20</sup> The speed trim system is a flight control system designed to improve the airplane's flight stability during operations in certain conditions when the autopilot is not engaged.

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# FAA Followed Its Risk Assessment Process, but Limitations Exist That May Impact Responses to Future Events

FAA has an established criteria and methodology for evaluating risks, including determining whether an aircraft should be grounded. FAA applied these processes in evaluating the safety of the MAX following the Lion Air accident. Following the Ethiopian Airlines accident, FAA waited for more detailed data before making a decision regarding MAX related actions, grounding the plane 3 days after the accident. While these actions were allowed under FAA's policies, we noted weaknesses in several areas, including the Agency's reliance on engineering judgment, outdated risk guidelines, difficulty with incorporating human factors such as pilot reactions to events, and inconsistent guidance and training.

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## FAA Followed Its Established Risk Assessment Processes After the Lion Air Accident

After the Lion Air accident on October 29, 2018, FAA followed its established process for evaluating risks for in-service fleets following safety events. This process, known as the Continued Operational Safety process, is contained in FAA's in-service aircraft safety order, the Monitor Safety/Analyze Data (MSAD) order,<sup>21</sup> which covers safety monitoring and risk assessment across all in-service fleets. FAA also uses its Transport Airplane Risk Assessment Methodology (TARAM) handbook, which provides additional guidance more tailored to the assessment of transport category airplane fleets, such as the Boeing 737 MAX.

FAA's MSAD order covers the Agency's process of receiving data from sources such as operators and manufacturers<sup>22</sup> and then determining the appropriate type of corrective action.<sup>23</sup> It also defines the key metrics that FAA staff should focus on when performing analysis of potential safety issues. FAA's TARAM handbook is designed to complement the safety order and outlines a primarily quantitative methodology for assessing risks. The handbook also states that any

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<sup>21</sup> FAA Order 8110.107A. Monitor Safety/Analyze Data. October 1, 2012.

<sup>22</sup> 14 CFR § 21.3 states that holders of type certificates must report failures, malfunctions, or defects that meet certain criteria, such as engine failures, malfunctions of airspeed instruments, or significant structural defects.

<sup>23</sup> The actual issuance of the corrective action such as airworthiness directives issued under 14 CFR Part 39 is outside of the MSAD process.

estimates included in the analysis should be empirically based, and not overly conservative, to allow for the correct prioritization of safety issues. The handbook provides specific guidelines for transport category aircraft fleets, as designated in the MSAD order (see table 1).

Table 1. Key MSAD Metrics and TARAM Guidelines

Risk Value	Definition	Purpose	Guideline
Total Uncorrected Fleet Risk	Predicted number of weighted events over the remaining life of the fleet if no corrective action is taken (Weighted by injury ratio).	Provides a long-term forecast of future risk if no corrective action is taken. This helps determine whether an unsafe condition might exist and is used to guide the decision for corrective action.	Corrective action when >.02 weighted events (accidents) for transport aircraft
Uncorrected Individual Risk	Individual probability of fatal injury per flight or flight hour	Risk calculation helps determine whether an unsafe condition may exist, and is used to guide the decision for corrective action.	Corrective action when > 1 per 10 million flight hours
Control-Program Fleet Risk	Number of fatalities <sup>24</sup> predicted during the control program (the period when corrective action is being accomplished.)	Helps evaluate the acceptability of candidate corrective actions.	Maximum risk within control program not >3 fatalities
Control-Program Individual Risk	The highest probability per flight hour, expected to occur during a reasonable number of future flights, that an exposed individual will be fatally injured before corrective action is accomplished.	Used to guide the decision for the urgency of the corrective action.	Urgent Action when >1 in 1 million flight hours
			Not airworthy when >1 in 100,000 flight hours

Source: FAA TARAM handbook

Following the Lion Air accident, FAA followed the processes outlined in the MSAD order and TARAM handbook, created a briefing paper about the accident, and organized staff to send to Indonesia to assist with the investigation while the Agency waited for official data. Boeing notified FAA on November 4, 2018, that the Flight Data Recorder from the accident indicated an airplane design safety issue. On November 6, Boeing issued a bulletin to 737 MAX 8 and MAX 9

<sup>24</sup> Per the TARAM handbook, some of the values and guidelines are expressed in terms of fatalities. These should not be viewed as predictive values. The TARAM risk values and risk level guidance represent a level or range and are not expectations of actual events.

operators that erroneous Angle-of-Attack data could result in uncommanded nose-down movement of the aircraft and emphasized pilot procedures to correct the issue. According to our email reviews, on the same day, FAA conducted a preliminary TARAM risk assessment that determined a need for urgent action.<sup>25</sup>

Subsequently, FAA issued an emergency AD on November 7, 2018. The AD instructed operators to revise their flight manuals and provided flight crews with procedures for counteracting the aircraft's nose-down movements due to erroneous Angle-of-Attack data under certain conditions. However, the emergency AD did not mention MCAS by name.<sup>26</sup> Agency officials stated that at the time, they were unaware of the full details of MCAS. FAA officials still believed that if MCAS activated erroneously, pilots would recognize its effects on flight, address it as a runaway stabilizer<sup>27</sup>—a failure scenario that is covered in 737 type rating training—and react accordingly.

FAA issued the emergency AD before the TARAM risk analysis was complete, which is allowed by FAA policy. The policy states that when FAA identifies an urgent unsafe condition that requires immediate corrective action, the Agency should start drafting an emergency AD or immediately adopted rule.<sup>28</sup>

Per FAA's process, the CARB reviewed the TARAM risk analysis on November 28, 2018<sup>29</sup> and supported the original decision to issue the emergency AD as an interim action. Specifically, the TARAM analysis confirmed that urgent action was necessary and that FAA would have had 3 days to address the issue with an interim action to stay within the established risk guideline.

The analysis further predicted that there would have been 76 more accidents over the 35-year life of the fleet without the issuance of the November 7, 2018, emergency AD, based on the in-service fleet of 250 airplanes at the time. However, even without the AD, the analysis still would not have recommended grounding the aircraft because the control program individual risk of 2.68 fatalities per 1 million flight hours remained below the TARAM guideline of 1 fatality per 100,000 flight hours.

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<sup>25</sup> Urgent action is necessary when an unsafe condition requires immediate corrective action, with FAA issuing either an emergency AD or an Immediately Adopted Rule. These can be started based on an FAA estimate that the time in which the action is required is too short to allow for normal public comment processes.

<sup>26</sup> On November 10, 2018, Boeing issued a message to operators that included a brief MCAS description.

<sup>27</sup> A technical fault resulting in continuous unintended movement of the horizontal stabilizer.

<sup>28</sup> An immediately adopted rule is a regulation published in the Federal Register without a public comment period. Immediately adopted rules are used when the required action must be accomplished in less time than prior public comment would allow.

<sup>29</sup> Prior to this, the CARB also held an informal meeting on November 7, 2018, and received an update on the issue on November 14, 2018.

FAA was aware that in addition to the emergency AD, a permanent design solution would be necessary to address the unsafe condition caused by unintended MCAS activation. The CARB held a subsequent meeting on December 12, 2018, to evaluate the need for further corrective action and the timeline. The CARB determined that an additional action to fix the MCAS software was required to further reduce risk. Specifically, the uncorrected fleet risk, with the emergency AD in place, still showed a projection of 15 weighted events<sup>30</sup> over the 35-year life of the fleet if the software fix was not implemented.<sup>31</sup>

Following the CARB's determination, Boeing proposed and FAA accepted a redesign of MCAS software that would include additional safeguards against unintended MCAS activation. This risk analysis also indicated that the previously published emergency AD mitigated risk sufficiently<sup>32</sup> to allow continued aircraft operation until July 2019, while the software fix was being developed and implemented on the existing fleet. In February 2019, FAA and Boeing agreed on a plan to develop a software fix, publish the related service information by April 19, 2019, and give operators until June 18, 2019, to implement the corrective actions. See exhibit D for a summary of the risk analyses following the Lion Air accident.

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## **FAA Waited for Detailed Data Before Grounding the MAX Fleet After the Ethiopian Air Accident**

Following the March 10, 2019, Ethiopian Airlines accident, FAA initiated its risk assessment process and had a staff engineer draft a TARAM analysis, per its policy. According to FAA officials, the Agency did not immediately ground the MAX following the accident because they wanted more detailed data before they could make an informed decision. This is supported by our review of emails from the period of March 10 through March 13, 2019. FAA received the preliminary flight data on March 11 and began to evaluate it. However, FAA faced challenges when trying to interpret the initial raw data,<sup>33</sup> which lacked enough specifics to

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<sup>30</sup> Weighted events represent accidents, adjusted by a factor known as the Injury Ratio, which includes potential fatal injuries to passengers and non-passengers.

<sup>31</sup> In this case, the fleet was projected to grow to 4,800 planes and be in service for 35 years. The analysis found that the uncorrected individual risk decreased to 2.82 fatalities per 100 million flight hours, which is less than the TARAM guideline of 1 fatality per 10 million hours.

<sup>32</sup> This was calculated using a guideline known as "Time to Outer Marker," which is the amount of time in which the Control Program Fleet Risk will remain under 3 fatalities.

<sup>33</sup> FAA reviewed Flightradar24 ADS-B data, however it only covered three minutes of the flight and lacked data fidelity. Subsequently, FAA contacted Aireon for the Space-Based ADS-B data, which initially provided rough plots, and later the raw data file. However, FAA did not fully understand the raw data at this time, and sent the information to the National Transportation Safety Board (NTSB.)

compare with the more detailed information that had been compiled from the Lion Air accident. In addition, FAA officials were receiving information regarding the configuration of the airplane at the time of the accident, which indicated that the accident might not be related to MCAS. This affected understanding of the accident's cause and analysis. Incomplete data delayed decision making within the Agency, as it was difficult to compute data without a reliable set of information.

FAA officials maintained their decision to not immediately ground the aircraft despite some internal and international concerns. Our review of emails and interviews of FAA officials revealed that individual engineers at the Seattle ACO recommended grounding the airplane while the accident was being investigated based on what they perceived as similarities between the accidents. Yet Agency officials at Headquarters and the Seattle ACO opted not to do so; instead, they waited for more detailed data to arrive. However, FAA officials did draft an order that would ground the MAX fleet if incoming data showed an association between the accidents.

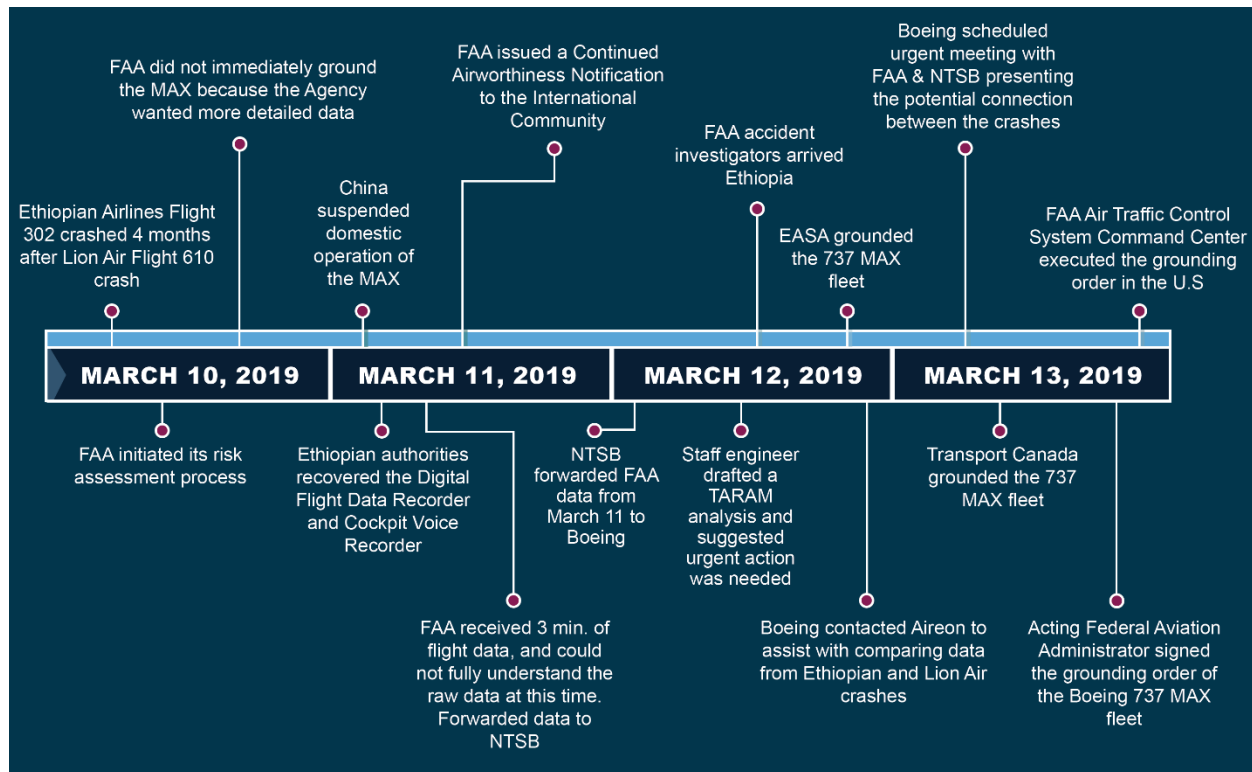
In addition, Agency officials expressed frustration that foreign civil aviation authorities were grounding the aircraft before they had data that linked the two accidents. FAA officials were standing by their previous assessments of the airworthiness of the airplane until the Agency completed its analysis. For example, one FAA aircraft certification executive emailed other aircraft certification executives and managers on March 11: "We want to work with any authority that has concerns with continued operation. It is early with regard to the Ethiopian accident investigation so it likely will be several days before we get better information. In the meantime we have no reason to question the safety of continued operations." On March 11, 2019, FAA issued a Continued Airworthiness Notification to the International Community (CANIC), which stated that the Agency did not yet have any data on which it could "draw any conclusions or take any action" and explained FAA's ongoing oversight of Boeing's development of a permanent fix for MCAS.

Once FAA received more detailed information, the Acting Federal Aviation Administrator took action. Specifically, by March 13, 2019, Boeing was able to interpret and plot the more detailed aircraft data following a discussion with the company that provided the data. Boeing's analysis indicated a potential link between the Lion Air and Ethiopian Airlines accidents. Boeing then notified FAA and held a presentation about the more detailed data and its analysis on the morning on March 13. Following this meeting, at the direction of the Acting Federal Aviation Administrator, the Agency prepared to ground the airplane, using the authority granted by 49 U.S.C. Sections 40113(a) and 46105(c). This is the only step in the grounding process that was mandated by Federal law or regulation. This was FAA's first grounding of a transport airplane fleet since the



Agency grounded the Boeing 787 Dreamliner in 2013. (See figure 2 for a more detailed timeline of events for the grounding of the 737 MAX.)

Figure 2. Timeline of Events Following the March 2019 Ethiopian Airlines Accident



Source: OIG analysis of FAA records

FAA's steps following the Ethiopian Airlines crash differed from its actions following the Lion Air crash in that the Agency did not convene an official CARB to decide a course of action. An FAA engineer drafted a preliminary TARAM risk analysis for the MAX on March 12, 2019. The preliminary analysis, which was based on the number of accidents, hours flown by the MAX, and the size of the fleet, showed a fleet risk for the MAX that was over 13 times the TARAM guideline. An FAA official noted at the time that the analysis suggested that there was a 25 percent chance of an accident in 60 days and that there were only "a matter of days" to implement a fix. However, this document was not completed and did not go through managerial review due to lack of detailed flight data. Agency officials declined to convene the CARB to evaluate the matter, citing a lack of robust data to inform their decision. According to the acting Seattle ACO manager at the time, once the Seattle ACO received the Automatic Dependent

Surveillance Broadcast (ADS-B)<sup>34</sup> data on March 13, 2019, they planned to hold an emergency CARB meeting, expecting to make a decision to ground the fleet via an emergency AD. However, shortly afterward, they were informed of the Acting Federal Aviation Administrator's plan to ground the fleet. That meant the CARB did not need to come to an immediate decision regarding the airworthiness of the MAX. Instead, the Seattle ACO decided to hold a CARB meeting for "informational purposes only" to inform the CARB of the ADS-B data and the impending grounding.

Although convening a CARB is typical following events per FAA's guidance, FAA's MSAD order instructs the Agency to take corrective actions before doing so, if necessary for urgent issues. In effect, FAA's actions aligned with its typical processes following events in waiting for detailed data before making a decision.

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## **Limitations in FAA's Risk Assessment Process and Data May Impact How the Agency Responds to Future Safety Events**

Although FAA's steps following the Lion Air and Ethiopian Airlines accidents were in line with its post-event risk assessment processes, we identified some areas that may impact the Agency's response to future events. Significantly, FAA's risk assessment processes rely in part on the judgment of engineers, who may lack relevant supporting data. These processes are further impacted by the use of outdated data limited to U.S.-based aircraft, a lack of quantifiable human factors data, and inconsistent guidance and training among ACOs.

### **FAA's Risk Assessment Process Relies in Part on Engineering Judgment That May Lack Relevant Supporting Data**

By design, FAA's risk assessment processes allow for significant flexibility in order to factor in the judgment of engineers. For example, the TARAM handbook states that FAA specialists should take the steps necessary to resolve the unsafe condition, before completing the risk-analysis process.<sup>35</sup> This engineering judgment, which can be expressed quantitatively during the risk assessment process, can play a significant role in FAA's decision-making.

For example, engineering judgment played a key role in FAA's acceptance of Boeing's initial corrective action plan and timeline following the Lion Air accident.

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<sup>34</sup> ADS-B is a satellite-based surveillance technology that also uses aircraft avionics and ground-based systems to provide information on aircraft location to pilots and air traffic controllers.

<sup>35</sup> One element of the Seattle Aircraft Certification Office's risk evaluation process includes several qualitative criteria. If any of those criteria are met, then FAA should take action to address the unsafe condition.

Specifically, FAA and Boeing's plan was largely dependent on FAA's assumption that issuing an emergency AD would be 99 percent effective at preventing future accidents due to pilots being able to recognize and address unintended MCAS activations. Based on this assumption, FAA accepted Boeing's plan to give operators until June 2019 to implement the corrective actions. Our analysis determined that decreasing this assumption to 90 percent effectiveness would have meant that per the TARAM guidelines, Boeing would have had less than 30 days to develop and implement a corrective action for MCAS. However, the analysis still would not have recommended an immediate grounding of the airplane.<sup>36</sup>

FAA officials stated that the assumption of 99 percent effectiveness was based on engineering judgment and was developed in consultation with operational evaluation pilots and certification flight test personnel. However, this judgment, although expressed numerically, was not informed by relevant quantifiable data. The subsequent Ethiopian Airlines accident highlighted potential limitations with that approach. FAA officials stated that it is difficult to estimate how pilots will react in real world situations due to the limited human factors data available to the Agency. They also indicated that at the time of the analysis, the Agency still did not understand the full impact of MCAS. While exercising engineering judgment is important, especially when analyzing infrequently occurring accidents, the lack of relevant quantifiable data limited FAA's analysis in this case.

### **The TARAM Guidance and Underlying Order Are Outdated, and Risk Guidelines Include Only U.S.-Based Airplanes**

FAA's MSAD order has not been updated since 2012. In addition, the TARAM handbook has not been updated since its inception in 2011. According to FAA subject matter experts, there were periodic attempts, most recently in 2018, to update the handbook by the division responsible for safety analysis policy. According to FAA officials, a recent attempt to update the handbook was delayed by events, including the Government shutdown of 2018–2019, the MAX accidents, and the COVID-19 pandemic.

Due to its age, the TARAM handbook uses risk guidelines determined using data from the 2000s for recommending corrective actions. Specifically, the handbook bases its individual risk guidelines on a 5-year range of data from 2002 to 2006, which had a higher accident rate for transport airplanes than more recent data from the past decade.<sup>37</sup> In addition, because these data only consider transport airplanes within the United States, accidents from Lion Air, Ethiopian Airlines, and

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<sup>36</sup> This guideline is known as "Control Program Individual Risk," and estimates the probability that an individual will be fatally injured before the corrective action is fully implemented.

<sup>37</sup> According to the TARAM handbook, this was derived using NTSB data.

other foreign operators are not included.<sup>38</sup> As a result, FAA is missing an opportunity to update the guidelines for determining potential corrective actions for transport airplanes manufactured within the United States. Using such data in risk assessments and decision making could improve the accuracy of future risk assessments.

### **FAA Faces Challenges When Including Human Factors in Its Risk Analysis**

The TARAM handbook and MSAD order do not adequately address human factors. The TARAM process becomes less effective when dealing with safety events involving human factors, particularly pilots' recognition and reaction to non-normal situations while in the cockpit. This is because the Agency lacks quantifiable data when analyzing human factors issues and real world situations, including varying pilot skill levels and the context for those events. As noted earlier, in the case of the MAX accidents, this led to an estimate that 99 percent of pilots would react correctly when presented with erroneous MCAS activations. This estimate greatly affected the amount of time that FAA and Boeing had to implement changes to the MAX, while staying within risk guidelines.

According to FAA's lead human factors technical specialist for aircraft certification, it is not possible to ensure the precision necessary for risk analysis when it involves predicting how people will react to complex situations. FAA is attempting to convert human factors data into a format usable in the TARAM process, and the National Academies of Sciences, Engineering, and Medicine also recommended that FAA create a baseline data set of human capabilities.<sup>39</sup> Still, the best overall approach to doing so is currently under debate. According to FAA officials, it will be difficult for FAA to complete this process due to the high variability of pilot responses during in-flight events due to the different contexts in which they occur.

### **Individual Aircraft Certification Offices Use Different Guidance and Training for Performing Risk Assessments, Which Could Lead to Inconsistent Approaches**

Due to a need for more specific guidance in unique situations than what the TARAM handbook and MSAD order contain, the Seattle ACO created an internal guidance document in late 2021. The Seattle ACO's guidance provides more details on how to evaluate potential unsafe conditions for transport category aircraft. In particular, it aims to clarify areas related to risk assessment,

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<sup>38</sup> FAA uses updated accident data and injury data known as injury ratios for TARAM analyses, which include international events.

<sup>39</sup> Evaluation of Transport Airplane Risk Assessment Methodology. National Academies on Sciences, Engineering, and Medicine. Aeronautics and Space Engineering Board. Division on Engineering and Physical Sciences. 2022.

determining the appropriate fleet size and retirement age, and FAA's fail-safe philosophy.<sup>40</sup> According to representatives from the Seattle ACO, this document, called the Transport Airplane Safety Manual (TASM), was not used for safety analysis of the MAX accidents, does not contain guidance that would have changed either of the ADs related to the accidents, and was not created as result of the accidents. It consists of lessons learned by the Seattle ACO and serves as a way to document preferred approaches for areas not covered by the TARAM handbook. The TASM provides examples of previous situations where specific analyses and refinement were created because the TARAM handbook did not provide adequate guidance in evaluating potentially unsafe conditions and determining corrective actions.

For example, the TASM provides guidance on how to calculate risk to maintenance or operational personnel. In one instance, a safety issue occurred when a latch on an engine cover was not manufactured properly, which could lead to the cover closing while a mechanic worked inside the engine. The TARAM handbook and worksheet do not offer guidance on risk analysis for this kind of event; therefore, the TASM supplements the analysis.

In addition, the TASM includes instructions on how to calculate risk for mixed passenger or cargo fleets, which are not addressed in the TARAM. The TASM also includes instructions on a risk measure known as "Time to Outer Marker," which measures the amount of time allowed to implement a fix before the acceptable risk guideline is reached.<sup>41</sup> This measure was included in the latest version of the MSAD order but is not included in the TARAM handbook. Finally, the TASM has guidance for calculating risk to account for potentially serious non-fatal injuries.<sup>42</sup> Specifically, the TASM developed new guidelines and guidance to determine safety action when the safety issue may lead to potential non-fatal injuries due to a range of factors, such as landing gear failure.

TASM is specific to the Seattle ACO. While the Seattle ACO has shared it with representatives from other ACOs, it is not required guidance or mentioned in either the MSAD order or the TARAM handbook. In addition, as noted by the National Academies, the purview of the Seattle ACO does not include all transport airplanes. As a result, FAA safety specialists may not be making consistent decisions when evaluating potential safety issues for transport category airplanes.

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<sup>40</sup> FAA's fail safe design philosophy is to ensure that no foreseeable single failure of a system or subsystem can prevent continued safe flight and landing.

<sup>41</sup> This is the maximum amount of time for manufacturers to address an unsafe condition. The TARAM Handbook states that the corrective action should be implemented as soon as it is practical.

<sup>42</sup> While the TARAM handbook mentions the possibility of an unacceptable rate of non-fatal injuries, it offers no guidelines on how to determine if that rate is "unacceptable."

In addition, FAA lacks guidance on training programs for conducting risk assessment activities. Currently, there are no mandated training requirements before an employee can complete a TARAM worksheet. Despite this lack of requirements, the Seattle ACO and the office responsible for TARAM policy conduct training classes with instruction on how to complete the TARAM worksheets. This is particularly important given the key role that engineering judgment plays in the post-event risk assessment process.

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## FAA Completed Recertification, Returned the 737 MAX to Service, and Is Refining the Certification Process Based on Lessons Learned

FAA completed the recertification of the 737 MAX on November 18, 2020. For the recertification, the Agency retained authority for approving all certification plans instead of delegating them to Boeing's ODA. FAA required Boeing to submit a comprehensive integrated System Safety Assessment to demonstrate the effects of Boeing's proposed changes on the safe operation of the airplane. The Agency also re-evaluated and approved Boeing's revisions to pilot training for the MAX and responded to comments from stakeholders and the public. While FAA is incorporating many of the lessons learned from the MAX recertification efforts for future projects, there are still new improvements and procedures that have not yet been codified by the Agency, and these improvements could be lost over time due to employee turnover.

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## FAA Retained Responsibility for Approving All Certification Plans for the MAX

Due to issues found during the re-evaluation of Boeing's System Safety Assessments following the Lion Air accident<sup>43</sup>—and to instill public confidence in the recertification—FAA elected to retain responsibility for approving all certification plans related to the airplane's return to service. This is in contrast to the aircraft's original certification, in which FAA reviewed Boeing's certification

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<sup>43</sup> As we reported in June 2020, Boeing's System Safety Assessments related to MCAS were not up-to-date, and did not include any mention of multiple MCAS activations.



plans<sup>44</sup> and delegated 87 percent of them back to Boeing 4 months before final certification of the 737 MAX 8, as allowed by FAA policy.<sup>45</sup>

FAA's evaluation of Boeing's revised flight control software began prior to the Ethiopian Airlines accident. Following the Lion Air accident in October 2018, the Boeing Aviation Safety Oversight Office and the Aircraft Evaluation Division began reviewing a version of the flight control software in anticipation of issuing an airworthiness directive in April 2019 containing Boeing's proposed changes to the flight control software and flight manuals. However, following the Ethiopian Airlines accident in March 2019, a series of events led to the timeline extending several times, eventually culminating in a 20-month review. These events included evidence that the crew in the Ethiopian Airlines accident used the stabilizer trim cutout switches but were unable to control the airplane using manual trim, difficulty in reviewing the initial System Safety Assessments submitted by Boeing for the revised flight control software, evaluation of an issue related to minimum separation of electrical wiring, and further potential failure modes discovered during flight testing that FAA required Boeing to address.

Boeing's re-design of MCAS included a new software safeguard to cross-check data between both Flight Control Computers and Angle-of-Attack sensors. The software re-design now compares both Angle-of-Attack sensors to validate their readings and will only allow MCAS and the speed trim system to activate if readings from the two sensors are within 5.5 degrees of each other. In addition, Boeing established limits on the degree to which MCAS can physically move the horizontal stabilizers.

FAA and Boeing also performed enhanced flight testing of the new MCAS design, with both in-flight and engineering simulators, as well as with the actual aircraft. Similar to the engineering process outlined above, FAA retained all compliance evaluations for these flight tests. Testing included maneuvering capability of the aircraft with the speed trim system activated and inactivated, performance testing at near-stall conditions, human factors testing, and evaluations of the physical forces necessary to use the manual trim wheel in the cockpit in the case of a disabled speed trim system. FAA also used domestic and international airline pilots to evaluate their responses to potential runaway stabilizer scenarios. Following these tests, FAA found the new designs met all compliance requirements.

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<sup>44</sup> According to FAA managers, it is typical for delegation to increase over time as the Agency gains confidence in Boeing's capabilities after initially retaining involvement.

<sup>45</sup> The ODA process allows FAA to delegate these findings of compliance and other activities that do not involve inherently governmental functions. These include authority reserved for FAA approval, regulatory activity, and other areas so designated by Agency guidance such as interpretations of airworthiness standards, development of issue papers, and special conditions.

In addition, FAA required changes to the regularly scheduled maintenance programs for the MAX before returning it to service. These included actions to ensure safe operations following long-term storage. Further, FAA mandated one-time actions to install new software and system design changes related to the Angle-of-Attack sensors and flight controls. These items were created by a Maintenance Review Board consisting of representatives from FAA, Transport Canada, and industry. See table 2 for a list of the key maintenance actions FAA required.

Table 2. Key Maintenance Actions Required Prior to Return to Service

Step	Type of Action
Ensure MCAS integrity via operational check	Scheduled Program
Operational check of stabilizer trim CUTOFF switch	Scheduled Program
Revised Flight Control Computer software upload	Pre-Return to Service
Stored airplane maintenance steps	Pre-Return to Service
Revision to Minimum Equipment List	Pre-Return to Service
Operational Readiness Flight	One-Time Test
Angle-of-Attack sensor system test	One-Time Test

Source: FAA Airworthiness Directive

However, FAA officials warned that while this extensive level of review was necessary due to the unique circumstances surrounding the MAX, the amount of effort involved is not replicable on every new certification project. As we reported in February 2021,<sup>46</sup> staffing levels and turnover in aircraft certification, namely at FAA’s Boeing Aviation Safety Oversight Office, are a concern, specifically in key areas such as software engineering and human factors. In February 2021, we recommended that FAA perform a workforce assessment at its Boeing oversight office to determine engineer resource and expertise needs. In addition, the Aircraft Certification Safety and Accountability Act of 2020<sup>47</sup> authorized additional funding for the recruitment and retention of certification staff in key areas. While

<sup>46</sup> *Weaknesses in FAA’s Certification and Delegation Processes Hindered Its Oversight of the 737 MAX 8* (OIG Report No. AV2021020), February 23, 2021.

<sup>47</sup> This Act was included in the Consolidated Appropriations Act of 2021, Pub. L. No. 116-260 (December 27, 2020).

FAA has made some progress, resource limitations still constrain the Agency's efforts, and our recommendation remains open.

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## **FAA Required Boeing To Submit a New Integrated System Safety Assessment Due to Multiple Issues in the Original and Revised Assessments**

Early in the return-to-service process, FAA and Boeing faced challenges in developing an understanding regarding the requirements for recertification of the MAX. Following the Lion Air accident, FAA initiated a review of the System Safety Assessments from the original certification related to MCAS. FAA noted that while the review did not find any noncompliance with regulations, an independent reviewer would not have been able to effectively review the System Safety Assessment as a standalone compliance document or understand the full system functionality and linkage with other systems and functions.

As part of the recertification process following the grounding of the MAX, FAA conducted in-depth reviews of Boeing's revisions for two previously approved System Safety Assessments. However, the Agency rejected<sup>48</sup> these individual revisions five times due to missing and incomplete required analyses. Specific examples of these early incomplete analyses included the fault tree analyses and hazard assessments that failed to adequately show the impact on systems affected by MCAS malfunction. While these submissions were similar to what FAA had accepted in the past, the fact that Agency engineers could not determine the potential effect of MCAS on the airplane led to the rejection of the submissions. As a result, FAA instructed Boeing to produce a new integrated System Safety Assessment for the speed trim system that would outline all effects of proposed system software changes. FAA did not initially accept Boeing's new integrated assessment and worked with Boeing to incorporate additional areas for improvement. These areas included:

- addressing open FAA and international civil aviation authority comments about recertification,
- requiring Boeing to state which regulation MCAS was designed to address,

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<sup>48</sup> According to FAA, two of these instances were not official rejections. Boeing elected to submit revised System Safety Assessments following conversations with FAA engineers.

- more clearly demonstrating that the assessments addressed all potential hazards associated with MCAS,
- resolving high-importance issues prior to flight testing, including manufacturers validating the expected pilot responses in failure scenarios and
- ensuring that there is no single failure or combination of failures that would prevent continued safe flight and landing.<sup>49</sup>

FAA officials and engineers stated that the integrated System Safety Assessment was essential for determining compliance with regulations, particularly when reviewing flight control systems. They also stated that integrated assessments should be added to future certification projects. Boeing stated that the company is preparing integrated System Safety Assessments for ongoing certification projects, specifically with the 777-9 and the 737 MAX 10.

However, there is no regulatory requirement for integrated System Safety Assessments, nor are these assessments mentioned in FAA's key guidance.<sup>50</sup> As reported by our office in February 2021 and NTSB<sup>51</sup> in September 2019, the key guidance is outdated and relies heavily on qualitative analysis and engineering judgment. Moreover, FAA's guidance does not reflect any improvements in the methods of validating human performance over recent decades, despite the Agency's longstanding recognition that such processes need to be improved. In February 2021,<sup>52</sup> we recommended that FAA assess this guidance related to engineering assumptions regarding pilot actions, pilot reaction times, and failure mode testing. FAA agreed to implement this recommendation by December 31, 2025.

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<sup>49</sup> This was accomplished by completing a Failure Modes Effect Analysis within the integrated System Safety Assessment, as well as submitting a Single and Multiple Failure Analysis, which was an internal Boeing document designed to "prevent simultaneous failure from a single threat event which causes loss of continued safe flight and landing."

<sup>50</sup> FAA Advisory Circular 25.1309-1A. June 21, 1988.

<sup>51</sup> NTSB Report No. ASR-19-01. *Assumptions Used in the Safety Assessment Process and the Effects of Multiple Alerts and Indications on Pilot Performance*. September 19, 2019.

<sup>52</sup> *Weaknesses in FAA's Certification and Delegation Processes Hindered Its Oversight of the Boeing 737 MAX 8* (OIG Report No. AV2021020), February 23, 2021.

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## FAA Accepted Boeing's Changes to Training and Procedures Prior to the MAX's Return to Service

During the 20-month recertification process, FAA reviewed and accepted Boeing's revisions to training and procedures before the Agency permitted the MAX to return to service. These revisions evolved and became more detailed as FAA and Boeing gathered more information about the revisions to MCAS and other changes required to recertify the aircraft.

After the Lion Air accident but before the Ethiopian Airlines accident, Boeing requested an additional self-administered training course for proposed MCAS software improvements for MAX pilots that were already qualified on the 737 NG. Boeing justified this because of the design similarities (approved during the original certification) between the two aircrafts' flight control systems. This meant that pilots who were qualified to fly a 737 NG airplane would still only need to complete self-guided reviews and computer-based courses to fly the MAX.

After Boeing submitted these requests, FAA operational test pilots from the Seattle Aircraft Evaluation Group reviewed the training and handling differences along with the MAX's redesigned flight control computer software in Miami, FL, on March 13, 2019. Then, based on this review, FAA approved Boeing's request for Level B (classroom or computer-based) training<sup>53</sup> on March 14, 2019. The Agency's review included evaluations of pilot reactions to MCAS activation in normal and non-normal situations, as well as the handling and training necessary to continue safe flight should MCAS fail. The approval for Level B training was provisional pending the issuance of an amended type certification of the 737 MAX that included Boeing's new software. This provisional approval was delayed once it became clear that recertification would not be completed as soon as Boeing and FAA had originally planned.

As the recertification progressed and the flight control software continued to change throughout 2019, FAA operational test pilots and certification engineers found more potential failures that needed to be flight tested, which resulted in changes to checklists used by pilots in non-normal situations. On January 15, 2020, Boeing formally proposed adding a Full Flight Simulator training module on how to handle unintended MCAS activation and runaway stabilizer issues. According to Boeing representatives, this was due to the length of time of the

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<sup>53</sup> FAA typically establishes a Flight Standardization Board when certifying large jets. It consists of members of the Aircraft Evaluation Division, FAA operations inspectors, representatives from the Office of Safety Standards, and other technical advisors if necessary. This board approves a manufacturer suggested rating of A-E for training in specific areas. These ratings determine the scope and delivery method of the proposed training.

grounding and to ensure pilots were comfortable with the changes. FAA later accepted this proposal and integrated these requirements into all pilot training for the MAX.

To evaluate Boeing's proposed training revisions, FAA and foreign regulators<sup>54</sup> formed a Joint Operational Evaluation Board, which evaluated the MAX in September and October 2020. The board used a combination of U.S.-based and foreign pilots to evaluate the differences between the revised 737 MAX with the new software and the 737 NG. It also helped set the requirements to operate the MAX following return to service.

FAA also approved Boeing's revisions to eight non-normal checklists that pilots can refer to in situations that they would not normally experience during routine flight operations.<sup>55</sup> FAA's Aircraft Evaluation Division validated these checklists as part of the recertification process, including the use of the checklists by domestic and international line pilots. See table 3 for a description of changes for each of the checklists.

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<sup>54</sup> The Joint Operational Evaluation Board consisted of representatives from FAA, Brazil, Canada, and the European Union.

<sup>55</sup> FAA Advisory Circular AC 25.1329-1C. "Approval of Flight Guidance Systems." May 24, 2016.



Table 3. Changes to Non-Normal Checklists for the 737 MAX

Checklist	Description of Change
SPEED TRIM FAIL <sup>56</sup>	Boeing updated the checklist to reflect that when the caution appears, speed trim will not be able available for the remainder of the flight.
Airspeed Unreliable	Boeing added a step allowing the flight crew to determine a reliable airspeed indication without referring to pitch-and-power reference tables.
AOA DISAGREE	Boeing simplified the checklist to direct the flight crew to the Airspeed Unreliable checklist when there is an indication that the left and right Angle-of-Attack vanes disagree.
ALT DISAGREE	The checklist now includes an additional step directing the flight crew to the Airspeed Unreliable Non-Normal Checklist if the IAS DISAGREE alert is also shown on the flight instruments.
Runaway Stabilizer	This was modified to include situations when uncommanded stabilizer movement occurs continuously or in a manner not appropriate for flight conditions. Furthermore, Boeing moved 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.
Stabilizer Trim Inoperative	Boeing modified the checklist to emphasize information concerning use of manual trim. A note to reduce airspeed for improving use of manual trim was added.
STAB OUT OF TRIM	Boeing revised the checklist to alert flight crews 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 flight crews not to take off when the alert is illuminated on the ground.
IAS DISAGREE	This NNC directs the flight crew to accomplish the Airspeed Unreliable NNC when the captain's and first officer's airspeed indicators disagree.

Source: OIG analysis

FAA and other foreign civil aviation authorities disagreed in one key area: the ability to silence the stick shaker alert<sup>57</sup> during non-normal situations. Foreign authorities, including the European Union Aviation Safety Agency and Transport Canada, wanted to grant pilots the ability to silence the stick shaker during non-normal situations, stating that it was a distraction to pilots. While FAA agreed with the idea that introducing a method to silence the stick shaker was a good idea, the Agency disagreed with the proposed solution of having pilots pull a circuit

<sup>56</sup> Items listed in capital letters have a cockpit alert associated with them.

<sup>57</sup> The stick shaker is an alert that warns the flight crew when the aircraft is close to a wing stall condition.

breaker, citing an existing regulation<sup>58</sup> that states that circuit breakers are not to be used as the primary means to remove power to airplane systems. In addition, FAA believes that pulling a circuit introduces more risk than the stick shaker alert because of the possibility of pulling the wrong circuit breaker and cutting power to another key system of the aircraft, and the difficulty accessing the circuit breaker from the pilots' normal seated position. According to Boeing, this disagreement does not affect the design of the airplane, and although it can be a distraction, it does not affect controllability of the airplane. As a result, pilots will have different non-normal checklist procedures based on the country of aircraft operation.<sup>59</sup>

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## FAA Requested and Responded to Stakeholder and Public Comments Prior To Recertifying the MAX

On August 6, 2020, FAA issued a Notice of Proposed Rulemaking for its airworthiness directive to rescind the grounding of the MAX fleet. Following the announcement, FAA received 230 comments. Organizations that submitted comments included airlines, pilots unions, and the union representing FAA certification engineers.<sup>60</sup> These comments fell into several key areas:

- **Concerns regarding the continued use of MCAS and reliance on Angle-of-Attack sensors.** Commenters stated that MCAS should not be on the plane. Other commenters raised concerns about MCAS activation being reliant on Angle-of-Attack sensors and preferred to have a dedicated switch designed to fully disable MCAS. In its Final Rule, FAA stated that the revised version of MCAS meets its safety standards, and there are safeguards built into the software design that either disable MCAS or only allow it to activate once per triggering event.
- **Angle-of-Attack position indicators.** Commenters raised concerns about the lack of mandatory Angle-of-Attack position indicators. FAA responded that such indicators are not required for compliance with design standards.
- **Flight crew interface.** Pilots associations, airlines, and foreign authorities expressed concerns about the amount of force necessary to control and

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<sup>58</sup> 14 CFR § 25.1357(f).

<sup>59</sup> Public Law No. 117-328 (December 29, 2022) requires that within 3 years of the certification date of the 737 MAX 10, all MAX aircraft in operation must include a means to shut off stall warnings.

<sup>60</sup> The National Air Traffic Controllers Association (NATCA) represents FAA's Aircraft Certification Service engineering bargaining unit.

manually trim the airplane, the lack of a means to suppress an erroneous stick shaker, and finally the length and complexity required for some of the non-normal checklists. Specifically, one pilot association and a main airline trade association were concerned that the Runaway Stabilizer Non-Normal checklist violated FAA's guidance, which states that checklists should have no more than three memory items for pilots to perform.<sup>61</sup> FAA's response emphasized the various evaluations of the manual trim system and checklists, as well as the Agency's extensive collaboration with foreign authorities for recertification.

- **Changed Product Rule.**<sup>62</sup> Several commenters expressed concern that the 737 MAX was still being certified as a derivative of the older 737 platform. Specifically, they expressed concerns that the 737 MAX does not fully comply with 14 CFR 25.1322, which deals with crew alerting.<sup>63</sup> FAA reiterated that the recertification of the MAX was based on addressing the specific unsafe conditions caused by the original MAX design.<sup>64</sup>

On November 18, 2020, FAA rescinded the grounding order and issued a final airworthiness directive, thus allowing the 737 MAX to return to service.

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## FAA Has Identified and Begun Implementing Lessons Learned Into Future Certification and Oversight Policies and Procedures

FAA has begun integrating lessons learned from the recertification of the MAX into future projects. These items were designed to address problems exposed following the original certification, including differences between the skill level of test pilots and airline pilots conducting routine flight operations, incomplete information sharing resulting in fractured analysis, and an incomplete understanding of the impact of individual systems at the airplane level. While the Agency has taken steps in some areas, it has not yet included all of the lessons learned into rulemaking, guidance, or other regulatory activities, due to multiple factors, including the length of time inherent in the Federal rulemaking process,

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<sup>61</sup> FAA Advisory Circular 120-71B. January 10, 2017.

<sup>62</sup> 14 CFR § 21.19, 14 CFR § 21.101 and Advisory Circular 21.101-A, known as the "Changed Product Rule."

<sup>63</sup> Flight crew alerts attract the attention of the flight crew, to inform them of specific airplane system conditions or operational events that require their awareness.

<sup>64</sup> In response to a previous audit report, FAA stated the Agency "is taking numerous steps to reform its certification process, including the Changed Product Rule." *Weaknesses in FAA's Certification and Delegation Processes Hindered Its Oversight of the 737 MAX 8*. OIG Report No. AV2021020. February 23, 2021.

the complexity of the issues involved, and the involvement of external or international parties.

Examples of FAA's improvements so far include:

- FAA has codified the requirement to use air carrier pilots as part of its Flight Standardization Board evaluations. This means commercial aviation pilots will help evaluate differences between training, checking, and handling, as well as evaluating the checklists for new aircraft. On December 27, 2021, FAA issued Notice 8900.606, which stated that Flight Standardization Board reviews must include the use of air carrier pilots of varying levels of experience for transport airplane type certification projects.
- In addition, in response to the Aircraft Certification, Safety, and Accountability Act<sup>65</sup> in February 2022, FAA announced an initiative to include a Technical Advisory Board in future certification projects. This initiative will focus on: incorporating the Technical Advisory Board early in certification processes; determining different levels of Board involvement; identifying new technologies, designs, or design features that could be catastrophic if they failed; and evaluating whether similar systems have potentially caused problems on other aircraft models or types.

However, other lessons learned have not yet been formally incorporated into FAA's processes. For example:

- **Integrated System Safety Assessments.** As described above, during recertification, FAA required Boeing to submit a new integrated System Safety Assessment—a document that had not been part of the MAX's initial certification. According to FAA and Boeing, integrated System Safety Assessments will be incorporated into the certification processes for future aircraft certifications—including new and amended type certificates for new airplane models. However, that agreement is not yet codified or incorporated into FAA guidance. As we reported in 2021,<sup>66</sup> FAA's main guidance for these assessments has not been updated since 1988.<sup>67</sup> While FAA has committed to revamping the guidance, these revisions are not currently scheduled to be complete until 2025. According to FAA, although integrated System Safety Assessments are

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<sup>65</sup> The Aircraft Certification, Safety, and Accountability Act was included as part of the Consolidated Appropriations Act for fiscal year 2021, Pub. L. No. 116-260 (December 27, 2020).

<sup>66</sup> *Weaknesses in FAA's Certification and Delegation Processes Hindered Its Oversight of the 737 MAX 8* (OIG Report No. AV2021020), February 23, 2021.

<sup>67</sup> FAA Advisory Circular 25.1309-1A. June 21, 1988.

allowed under current regulations, there are no plans to add them to forthcoming revisions of regulations or guidance.

- **Communication between FAA and Boeing.** While FAA and Boeing have made extensive efforts to improve communication and formalize documentation throughout the certification process, there are areas for improvement. For example, as noted above, FAA rejected five of the System Safety Assessments submitted by Boeing during the early stages of recertification of the MAX, including two that were “informally rejected” during discussions between FAA and Boeing engineers when it became apparent that they were missing information that FAA needed to review the documents. Based on our conversations with FAA and Boeing, this informal rejection was intended to speed the process along, and provide Boeing with feedback, instead of waiting for lengthy official formal documentation to be exchanged. However, this informal approach raises the risk of miscommunication between FAA and Boeing or potential mistakes during the certification process. For example, in February 2021, we reported that communication and coordination gaps between FAA and Boeing impeded knowledge sharing between the two entities, which resulted in FAA engineers being unaware of a change in the parameters of MCAS activation.

Until these issues are resolved, FAA may not integrate all of the beneficial activities and lessons learned from the recertification effort and may not be well positioned to address the impact of future safety events.

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## Conclusion

FAA recertified the 737 MAX on November 18th, 2020, after an extensive 20-month effort to return the aircraft to service. The Agency followed established processes after the accidents and during the extensive return to service effort. However, outdated guidance and a lack of usable data when analyzing human factors in real world situations created challenges in achieving its goal of returning the 737 MAX to service safely. Updating Agency guidance and incorporating lessons learned from the return to service effort will be essential to ensure the highest level of safety of transport category airplanes.

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## Recommendations

To improve FAA’s risk assessments and determination of corrective actions, we recommend that the Federal Aviation Administrator:

1. Document the process by which key safety decisions, such as a potential grounding of an aircraft fleet, are made when the Agency identifies that urgent action is necessary.
2. Revise the Transport Airplane Risk Assessment Methodology (TARAM) handbook to incorporate current safety data, including available international data when appropriate.
3. Review the TARAM handbook's quantitative safety guidelines to determine if they meet the Agency's needs, and implement identified corrections as appropriate.
4. Formalize training requirements for engineers responsible for completing TARAM analysis, as well as managers responsible for reviewing the analysis.
5. Review the TARAM and Transport Airplane Safety Manual (TASM), address any identified key differences between the two documents, and integrate TASM into TARAM when appropriate.
6. Incorporate integrated System Safety Assessments into regulations or Agency guidance for future transport category airplane certification projects.
7. Identify lessons learned related to the application of the 737 MAX recertification and the Continued Operational Safety process that have not yet been addressed and include them into airplane certification and safety evaluation processes.

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## Agency Comments and OIG Response

We provided FAA with our draft report on March 2, 2023 and received its formal response on March 31, 2023. FAA's response is included in its entirety as an appendix to this report. FAA concurred with all seven recommendations and provided appropriate actions and planned completion dates. Accordingly, we consider all recommendations resolved but open pending completion of the planned actions.

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## Actions Required

We consider all seven recommendations resolved but open pending completion of the planned actions.

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## Exhibit A. Scope and Methodology

This performance audit was conducted between May 2021 and March 2023. We conducted this audit in accordance with generally accepted Government auditing standards as prescribed by the Comptroller General of the United States. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

This report is in response to requests from Secretary Elaine L. Chao and members of Congress to determine and evaluate FAA's process for grounding and recertifying the Boeing 737 MAX series of aircraft. This is our third report on FAA's certification of the 737 MAX and follows our first and second reports, issued on June 29, 2020, and February 23, 2021, respectively.

To obtain detailed, factual information regarding FAA's aircraft grounding and recertification process of Boeing's 737 MAX, we met virtually with FAA aircraft certification officials from Washington, DC, and Seattle, WA. We reviewed FAA's Continued Operational Safety guidance for conducting risk assessments and identifying corrective actions, including the FAA Order on Monitor Safety Analyze Data (Order 8110.107A) and the TARAM handbook. We obtained and reviewed the formal risk analysis worksheets conducted by the Seattle ACO Branch following the Lion Air accident, and the draft worksheet following the Ethiopian Airlines accident. We also reviewed the respective CARB meeting minutes and presentations. To ensure accuracy, we compared our reviews of source documents against information we obtained from interviews with FAA officials.

We received briefings from FAA's Aircraft Certification Service, System Oversight Division and Compliance and Airworthiness Division, as well as the Flight Standards Service and Aircraft Evaluation Group located at FAA's Northwest Mountain Regional Office. In addition, we conducted interviews of FAA managers; flight control engineers; and certification, oversight, and flight test management personnel. We also interviewed and received briefings from Boeing, which included further documentation regarding certification plans, internal system safety analyses, MCAS-specific requirements and testing documents, internal flight test reports, and updates regarding return-to-service actions and MCAS software revisions. We also met with industry associations, including a National Air Traffic Controllers Association representative for FAA aircraft certification engineers in order to look at issues raised over the course of the MAX's recertification. Our briefings and interviews primarily focused on the timeframe from the first 737 MAX accident until the final recertification and return to service of the 737 MAX.

We reviewed and analyzed recertification plans and associated deliverables, issue papers, internal correspondence, and safety analyses conducted during the recertification process and following the 2018 and 2019 accidents, and flight test documents pertaining to the Boeing 737 MAX recertification. We reviewed electronic correspondence sent between FAA staff and employees during and after the accidents, as well as throughout the early recertification process. Specifically, we analyzed emails sent from various FAA officials from October 29, 2018, to April 30, 2019. We used these emails to confirm the events leading to the grounding of the 737 MAX, and as a real-world example and demonstration of FAA's Continued Operational Safety process.



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## **Exhibit B. Organizations Visited or Contacted**

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### **Federal Aviation Administration**

Aircraft Certification Service:

System Oversight Division

Boeing Aviation Safety Oversight Office

Compliance and Airworthiness Division

Northwest Flight Test Section

Seattle Aircraft Certification Office

Policy and Innovation Division

Systems Policy Branch

Flight Standards Service:

Seattle Aircraft Evaluation Group

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### **Other Organizations**

Boeing Commercial Airplanes

National Air Traffic Controllers Association

Coalition of Airline Pilots Associations

Air Line Pilots Association

Southwest Airlines Pilots Association

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## Exhibit C. List of Acronyms

DOT	Department of Transportation
OIG	Office of Inspector General
FAA	Federal Aviation Administration
ACO	Aircraft Certification Office
AD	Airworthiness Directive
ADS-B	Automatic Dependent Surveillance-Broadcast
ATC	Amended Type Certificate
CANIC	Continued Airworthiness Notification to the International Community
CARB	Corrective Action Review Board
ICAO	International Civil Aviation Organization
MCAS	Maneuvering Characteristics Augmentation System
MSAD	Monitor Safety/Analyze Data
NTSB	National Transportation Safety Board
ODA	Organization Designation Authorization
TARAM	Transport Airplane Risk Assessment Methodology
TASM	Transport Airplane Safety Manual

## Exhibit D. Results of Lion Air TARAM Risk Analyses Reviewed by the Corrective Action Review Board

Risk Value	Guideline	Pre Mitigation (11/28/18 CARB)	Guideline Exceeded?	Post Emergency AD (12/12/18 CARB)	Guideline Exceeded?
Total Uncorrected Fleet Risk <sup>68</sup>	Corrective action when >.02 weighted events.	76.3 (weighted events) 76.3 (accidents)	Yes	15.4 (weighted events) 14.6 (accidents)	Yes
	Corrective action when >3 fatalities <sup>69</sup>	14,489 fatalities	Yes	2,921 fatalities	Yes
Uncorrected Individual Risk	Corrective action when >1 fatality per 10 million flight hours. ( $10^{-7}$ )	2.68 fatalities per one million flight hours ( $2.68 \times 10^{-6}$ )	Yes	2.82 fatalities per one hundred million flight hours ( $2.82 \times 10^{-8}$ )	No
Control Program Fleet Risk	Maximum risk within control program not >3 fatalities	2.84 fatalities	No	2.01 fatalities	No
Control Program Individual Risk	Urgent action when >1 in one million flight hours ( $10^{-6}$ )  Not airworthy (i.e., grounding) when >1 in 100,000 flight hours ( $10^{-5}$ )	2.68 fatalities per one million flight hours ( $2.68 \times 10^{-6}$ )	Yes (Urgent)	2.82 fatalities per one hundred million flight hours ( $2.82 \times 10^{-8}$ )	No
TARAM Recommendation		Issue urgent AD as interim action.		Airplane design change required to mitigate residual risk.	

Source: OIG Review of FAA Lion Air Accident TARAM Risk Analyses

<sup>68</sup> Fleet risk guideline is in weighted events, which is adjusted by the Injury Ratio (Ratio of occupants fatally injured.)

<sup>69</sup> The Seattle ACO uses a proposed change from a draft 2014 revision of the handbook, which limits the number of fatalities for larger airplanes. Specifically, fatality guideline when Exposed Occupants value is 150 or above, and they use the weighted event (equivalent planeload) guideline when Exposed Occupants is less than 150.

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## Exhibit E. Major Contributors to This Report

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SENIOR ANALYST

ANALYST

CHIEF COMMUNICATIONS OFFICER

DEPUTY CHIEF COUNSEL

SUPERVISORY VISUAL  
COMMUNICATIONS SPECIALIST

VISUAL COMMUNICATIONS  
SPECIALIST

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## Appendix. Agency Comments



### Federal Aviation Administration

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## Memorandum

Date: March 31, 2023

To: Nelda Z. Smith, Assistant Inspector General for Aviation Audits

From: Erika Vincent, Acting Director, Office of Audit and Evaluation, AAE-1

Subject: Federal Aviation Administration's Response to Office of Inspector General (OIG) Draft Report: FAA Has Completed 737 MAX Return to Service Efforts, but Opportunities Exist to Improve the Agency's Risk Assessments and Certification Processes

ERIKA S  
VINCENT

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VINCENT  
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The mission of the Federal Aviation Administration (FAA) is to provide the safest, most efficient aerospace system in the world. The FAA, in close coordination with aerospace stakeholders, has achieved a remarkable advancement in aviation safety. Over the past two decades, commercial aviation fatalities in the U.S. have decreased significantly. However, as evidenced by the two fatal accidents in 2018 and 2019 and the subsequent process of grounding the Boeing 737 MAX 8 and then returning it to service, the FAA—based on its analysis, the findings of several independent reviews, and OIG recommendations—fully recognize that there are opportunities to improve the agency's risk assessments, certification processes, and continued operational safety processes.

The FAA is fully committed to adopting and conscientiously implementing risk-mitigating measures that will improve safety outcomes and have already begun the work of updating guidance and incorporating lessons learned from the 737 MAX's return to service.

- The FAA has drafted an update to the Monitor Safety/Analyze Data (MSAD) order that will document the process by which key safety decisions, such as a potential grounding of an aircraft fleet, are made when the FAA identifies that urgent action is necessary. This action is being taken in response to Section 130 of the Aircraft Certification, Safety, and Accountability Act, Pub. L. 116-260 (the Act). The FAA anticipates publication of the revised order by December 2023.
- The FAA is also working to update the Transport Airplane Risk Assessment Methodology (TARAM) handbook to incorporate lessons learned from the 737 MAX accidents. In response to Section 130 of the Act, the FAA commissioned the National Academy of Sciences, Engineering, and Medicine (NASEM) to review the methodology and effectiveness of TARAM. NASEM published its final report in August 2022. The report contained 13 recommendations that align with the OIG recommendations for improving the

effectiveness of the TARAM and other supporting activities. As a response to those recommendations, the FAA developed and presented a work plan to congressional staff in September 2022.

The work plan includes revising the TARAM handbook and the FAA Order 8110.107, Monitor Safety/Analyze Data, to include better industry data, other methods or modules, such as human reliability analysis, uncertainty, high visibility events, and non-fatal accidents, and independent/quality peer reviews to help improve quantitative analysis and better decision-making for appropriate corrective actions. The FAA is also developing and instituting formal training for the FAA analysts and managers on the use of TARAM.

- The FAA plans to amend title 14, Code of Federal Regulations, section 25.1309 to improve aviation safety by making system safety assessment (SSA) certification requirements more comprehensive and consistent. With the rulemaking package, the planned update of the FAA SSA guidance, Advisory Circular (AC) 25.1309-1B, will include guidance on the appropriate use of an integrated evaluation of the SSAs taken together to verify that the airplane as a whole meets all the applicable requirements. This is described in the AC as Aircraft Safety Assessment (ASA). The use of ASA is not a requirement, as it is one means, but not the only means, of meeting the requirements of the SSA rule. The updated guidance accompanies the rulemaking on SSA for transport category airplanes and is currently open for public comment. We anticipate the issuance of the final rule and guidance material by the third quarter of 2024.
- The FAA received numerous recommendations from many sources including, but not limited to, OIG, the Department of Transportation Special Committee for the MAX, the Joint Authorities Technical Review, and the National Transportation Safety Board resulting from the 737 MAX accidents. As we incorporate these recommendations, we also continue to look for additional opportunities to apply lessons learned. We have planned research and committees to further explore areas such as human factors, certification, and safety evaluation processes.

Based on our review of OIG’s draft report, the FAA concurs with the recommendations as written and plans to complete actions to implement the recommendations as noted below.

<b>Recommendations</b>	<b>Target Action Dates</b>
1	September 30, 2023
2 through 5	March 31, 2025
6 and 7	September 30, 2024

We appreciate this opportunity to respond to the OIG draft report. Please contact Erika Vincent at [erika.vincent@faa.gov](mailto:erika.vincent@faa.gov) if you have any questions or require additional information about these comments.

U.S. Department of Transportation  
Office of Inspector General

# Fraud & Safety Hotline

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(800) 424-9071

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