Report to Executive Director, FAA Aircraft Certification Service:

Technical Advisory Board on the Design Change to the B737 MAX Maneuvering Characteristics Augmentation System

Final Report:

November 18, 2020

Executive Summary

Background

The Federal Aviation Administration (FAA) is overseeing The Boeing Company's (Boeing) design change to the maneuvering characteristics augmentation system (MCAS) on Boeing Model 737-8 and 737-9 airplanes (known as B737 MAX airplanes). MCAS is part of the speed trim system (STS) that enhances handling qualities in the pitch axis in certain speed/angle of attack regimes. Configuration changes (engine size and placement) unique to the B737 MAX led to the MCAS design to maintain consistent handling characteristics with earlier versions of the Boeing B737 family.

On October 29, 2018, Lion Air flight 610 (JT610), a Boeing Model 737-8 airplane, crashed approximately twelve minutes after takeoff in Jakarta, Indonesia. On March 10, 2019, Ethiopian Airlines flight 302 (ET302), also a Boeing Model 737-8 airplane, crashed approximately six minutes after takeoff in Addis Ababa, Ethiopia. The B737 MAX automated flight control system is an area of interest in both accidents. The FAA determined that the implementation of a Technical Advisory Board (TAB), consisting of an independent team of aircraft safety, system, and flight test experts was necessary to evaluate the redesign of the automated flight control system/MCAS. The TAB used an established process to provide an independent technical evaluation of the B737 MAX MCAS.

Technical Advisory Board Review Tasks

The TAB was tasked to evaluate Boeing's redesign of the MCAS. The purpose was to directly inform the FAA's decision making on MCAS approval and return of the B737 MAX airplane to service. These tasks included examining and dispositioning relevant facts, including all identified unsafe conditions regarding the JT610 and ET302 accidents, in accordance with 14 CFR 21.21 (which relates to the issuance of type certificates). This evaluation encompassed several broad areas, including the following:

- A review of all MCAS continued operational safety data and information gathered to date;
- A review of the technical approach for key design features that meets the compliance requirements set forth by the type certificate;
- A review of the item requirements and design, as defined under the certification standard, to ensure that all items have been complied with, including dispositioning of any open problem reports;
- A review of the failure modes of the redesign, to show that they are reasonably manageable by line pilots; and
- A review to ensure that proposed training programs for the redesign are appropriate, including a review of the work done by the Flight Standardization Board (FSB).

The TAB evaluated the B737 MAX MCAS design changes by conducting design reviews, procedure evaluations, and training assessments. These evaluations were conducted, taking into consideration representative flight conditions while maneuvering throughout the normal, operational, and limit flight envelopes that could be simulated in the Boeing engineering simulator (eCAB). The TAB evaluations also included desktop data reviews, eCAB testing, and training development reviews.

Results – Return-to-Service Action Items

The TAB found that the MCAS design changes are compliant and safe to support a return to service of the B737 MAX. The TAB's findings were contingent on the satisfactory resolution of the following action items. These action items were completed by the Boeing Aviation Safety Oversight Office (BASOO), Boeing, or the FAA's Aircraft Evaluation Group (AEG), as noted.

These action items were not based on the BASOO certification processes, as the TAB evaluation was conducted independent of the BASOO certification process and prior to the completion of the BASOO certification data review activities.

Action Item	Description of Action	Responsible Group
1	As an extension of the TAB review, complete an audit of Boeing's development assurance process as documented in their development assurance plan. Action item closed. Audit completed. The TAB evaluated and accepted the Development Assurance Accomplishment Summary document.	BASOO
2	Submit further analysis and test data to ensure proper functional integration of the spoiler system with the trim system and MCAS to include a top down assessment, or equivalent, which verifies the bottom up single and multiple failure (S&MF) analysis adequately covered combinations of speed trim system and spoiler system failures not shown to be extremely improbable. Action item closed. Based on TAB review of the Boeing closeout memorandum and associated reference documents. Discussion in a meeting between Boeing and the TAB on September 23, 2019 led to the creation of a document to explain how Boeing's Airplane Functional Hazard Assessment (AFHA) and System Functional Hazard Assessments (SFHAs) for the B737 MAX work together to form a robust top-down analysis for airplane and system-level functions, and how that top-down analysis is verified by the bottom-up S&MF analysis. The TAB evaluated and accepted the analysis.	Boeing

Action Item	Description of Action	Responsible Group
3	Submit the final version of the MCAS fault trees. Action item closed. Boeing provided the final version of the integrated system safety assessment (iSSA) dated August 25, 2020, which was accepted by the TAB.	Boeing
4	Submit the complete root cause analysis for the Auto Stabilizer Trim Monitor error in the fault tree for the Low Altitude Stabilizer Runaway failure condition (design escape). Action item closed. Boeing provided close out coordination sheet, June 19, 2019, which references the root cause analysis. The TAB reviewed and accepted the root cause analysis.	Boeing
5	Boeing to address the FCC CPU and memory postulated failure issue discovered during eCAB certification testing. Action item closed. The TAB evaluated new monitors to detect failures in P12.1.2 and evaluated thresholds by conducting eCAB testing. Boeing provided iSSA with monitor coverage dated August 25, 2020. The TAB evaluated and accepted the iSSA.	Boeing
6	Ensure the Speed Trim Fail procedure in the Quick Reference Handbook (QRH) encompasses both the speed trim function and the MCAS function. Action item closed. Boeing has incorporated changes in the Boeing QRH. The TAB has evaluated the changes to the Boeing QRH and found them acceptable.	Boeing/AEG
7	Add angle of attack (AOA) DISAGREE to the list of additional information as possible evidence of an AIRSPEED UNRELIABLE condition in the QRH. Action item closed. Boeing has incorporated changes in the Boeing QRH. The TAB has evaluated the changes to the Boeing QRH and found them acceptable.	Boeing/AEG

Action Item	Description of Action	Responsible Group
8	AEG to discuss with the Certification Management Team (CMT) and other stakeholders to consider incorporating IAS DISAGREE and AOA DISAGREE into Airspeed Unreliable Checklist so that it is titled Airspeed Unreliable or IAS DISAGREE or AOA DISAGREE, similar to the B747 checklist. Action item closed. The TAB concluded that with the enhanced training package, pilots will be able to successfully complete the separate IAS DISAGREE and AOA DISAGREE NNCs. This was also validated in the Joint Operations Evaluation Board (JOEB) activity and supported by B737NG service history. The TAB observes that there is a potential for confusion and misunderstanding when QRHs (or other documents) constructed by individual CAAs or operators differ from the AFM. The TAB observes that guidance on this subject in AC 25.1581-1 conflicts with the rules in 14 CFR 25.1581 through 25.1587, and that clearing up this conflict would improve oversight and reduce confusion.	Boeing/AEG
9	Submit the final version of Level B training (i.e., computer-based training) to the TAB for review. Action item closed. TAB reviewed all level B training and Boeing incorporated appropriate changes to the level B training as documented in the FSB report. The TAB noted that FSB report Appendix 7 requires a one-time full flight simulator training profile. The TAB reviewed that one-time simulator training and found it acceptable.	Boeing/AEG
10	Identify if special emphasis training for B737 series trim wheel forces awareness (including manual trim force requirement) is appropriate. Action item closed. Boeing provided and the TAB accepted Boeing Report, *737-8/-9 Stabilizer Trim Wheel Forces*, and trim awareness training per FSB report.	Boeing/AEG

Action Item	Description of Action	Responsible Group
11	Change STABILIZER TRIM to SPEED TRIM in the ATA 27 Flight Control row, remarks column contained in the Flight Standardization Board Report (FSBR) differences table, FROM BASE AIRCRAFT B-737-800 TO RELATED AIRCRAFT B-737-8. Action item closed. FAA incorporated the intent of the change as documented in the FSB report appendix 3 Differences Tables/Design ATA 22 Autoflight.	Boeing/AEG

Results – Future Action Items

Additionally, the TAB identified eight future action items that should be addressed by Boeing, the Seattle Aircraft Certification Office Branch (SACO), BASOO, Civil Aviation Authorities (CAAs), or AEG in a timely manner, as determined by the FAA Administrator. These future action items are not a prerequisite for returning the aircraft to service. The reason that these future action items are not required to be completed prior to returning the aircraft to service is because they are broader in scope than the B737 MAX MCAS enhancement action items. Additionally, they generally apply to the B737 NGs (Boeing Model 737-600, -700, -700C, -800, -900, and -900ER series airplanes are known as Next-Generation, or B737 NG airplanes), which have over 190,000,000 flight hours of unaffected service without the B737 MAX MCAS design features.

Future Action Item	Description of Future Action	Responsible Group(s)
1	Provide the root cause analysis for why implementation of the “AOA DISAGREE” message did not meet the design requirements. The “AOA DISAGREE” message was supposed to be standard on all airplanes. However, the “AOA DISAGREE” message was an option that was tied to the AOA Indicator option. Action item closed. Boeing provided close out coordination sheet, dated November 5, 2019 which references the root cause analysis. The TAB reviewed and accepted the root cause analysis.	Boeing

Future Action Item	**Description of Future Action**	**Responsible Group(s)**
2	Work with the head up display (HUD) supplemental type certificate (STC) holder to include the requirement for the B737 MAX HUD STC to include the "AOA DISAGREE" message. Action item closed. SACO confirmed STC design change during B737-10 certification. Retroactive incorporation will be based on SACO corrective action review board (CARB) process.	SACO
3	Prioritize the indicated airspeed (IAS) DISAGREE alert appropriately. This will assist pilots in prioritizing their actions in the high-workload environment that could result from an AOA DISAGREE, such as during takeoff, climb-out, approach and landing. Action item open: Requires a Boeing commitment for a longer-term solution.	Boeing
4	Add the notes from the QRH Stab Trim Inop procedure to the Runaway Stabilizer procedure. Action item closed: Boeing has incorporated changes in the Boeing QRH. The TAB has evaluated the changes to the Boeing QRH and found them acceptable.	Boeing/AEG
5	Evaluate the manual trim wheel control forces in the B737 MAX full flight simulator (FFS) to determine if exceptional pilot strength, alertness, or skill is required for controllability and maneuverability of the aircraft. Action item closed: Boeing provided and the TAB reviewed/accepted Boeing Report, *737-8/-9 Stabilizer Trim Wheel Forces* to verify exceptional pilot strength, alertness, or skill is not required for controllability and maneuverability within the certificated envelope of the aircraft.	Boeing, BASOO, AEG, or both

Future Action Item	**Description of Future Action**	**Responsible Group(s)**
6	Boeing to add step (if necessary) autothrottle disengage in Stabilizer Trim Inoperative checklist in QRH. Action item open: Boeing should evaluate this issue further via normal process post RTS to determine if adding a step about autothrottle usage is warranted.	Boeing
7	Analyze the initial, recurrent, transition, and upgrade training needed to provide the proficiency and currency requirements for air carriers. Identify the kinds of flightcrew interactions with the equipment that can be reasonably expected in service by qualified flightcrew trained in their use. Action item open: FAA should develop an action plan to engage ICAO and CAAs.	International Civil Aviation Organization (ICAO) or CAAs, or both
8	At the earliest regular training event, pilots of all B737 series airplanes should receive special emphasis training on trim system understanding, awareness, and use. Consideration should be given to broadening this training recommendation to pilots of all transport category airplanes. Action item open: TAB reviewed and accepted special emphasis training on trim system understanding, awareness, and use on the B737 series airplanes as documented in the FSB report. FAA to follow-up to determine if special emphasis training should be given to all transport airplanes types and, if so, establish the necessary communications via inspector guidance during training program approval.	FAA/ CAAs/Industry

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1. Technical Advisory Board Process

The TAB is an independent team of experts who are not routinely involved in certification of the product being certificated. The TAB evaluates efforts by the cognizant FAA certification office and the applicant associated with a design or redesign of a system to inform agency decision making as appropriate to the certification issue. The TAB challenges the assumptions and design decisions made by the applicant and overseen by the cognizant FAA certification office. The TAB may examine data and other information as extensively as necessary to conduct the following activities:

- Review any design changes and the overall approach to demonstrate compliance with regulatory standards;
- Review available data related to the design change to confirm that it minimizes expected in-service failures;
- Review relevant failure modes that can affect the pertinent system(s) and confirm that the design change(s) mitigates the hazards;
- Review approach for software certification, including definition and execution of requirements with relevant suppliers and disposition of software problem reports;
- Review training program changes to confirm outcomes of the Flight Standardization Board evaluation; and
- Submit a final report and recommendation to the Executive Director of the Aircraft Certification Service.

1.1 Technical Advisory Board Team Bios

Regina Houston – Chief of the Aviation Safety Management Systems Division, and Acting Chief of the Safety Information Systems Division, Volpe National Transportation Research Center

Regina Houston joined the Volpe National Transportation Research Center in 1991 where she is Chief of the Aviation Safety Management Systems Division and Acting Chief of the Safety Information Systems Division. Ms. Houston has over 35 years of experience in research and development of automation for transportation safety. During her most recent 25 years, Ms. Houston has focused on the aviation domain. She is recognized for her expertise in safety management systems and the principals of system safety. Ms. Houston has extensive experience in re-engineering and aligning automated systems, models and simulations to support changes in aviation business processes, policy and regulations; and evolving transportation safety goals and objectives. She often serves as a subject matter expert to assess and develop integrated risk profile models and assist aviation safety inspectors in risk-based decision making.

Ms. Houston was recognized for her work in aviation safety by receiving the U.S. Department of Transportation Secretary's Award for Excellence and the Dr. Frank F.C. Tung Award. She is also the recipient of the United States Department of Transportation (USDOT) Office of the Assistant Secretary for Research and Technology Award for her innovative approaches to using automation in aviation safety and the USDOT Research and Innovative Technology Administration Award for Technical Leadership.

Ms. Houston received an MS degree in Operations Research from George Washington University; an MBA from the Harvard Business School; and a BS degree in Civil Engineering from the Massachusetts Institute of Technology. She is also a Project Management Institute certified Project Management Professional (PMP).

Steven R. Jacobson – Systems Engineering, Integration and Project Formulation at NASA Armstrong Flight Research Center

Mr. Jacobson served as Chief of the Systems Engineering and Integration Branch from 2018-2020 at the NASA Armstrong Flight Research Center in Edwards, CA. He previously served as the Chief of the Dynamics and Controls Branch from 2007-2018.

Mr. Jacobson has 30 years of experience in atmospheric flight research and flight test of fixed wing aircraft and spacecraft, with a focus on flight controls, handling qualities, and flight dynamics.

Mr. Jacobson has an extensive background in commercial aviation safety. In 2008, served as the Technical Integration Manager within NASA ARMD's Aviation Safety Program. In 2009, Mr. Jacobson led a team of NASA, FAA and Volpe subject matter experts to examine the root causes of large transport loss of control and developed NASA research areas for preventing aircraft loss of control accidents. From 2010-2012 he served as a NASA technical representative for the Commercial Aviation Safety Team Joint Safety Analysis Team (CAST JSAT) for aircraft state awareness. This government and industry team analyzed commercial aviation loss-of-control accidents that were caused by a lack of aircraft state of awareness (ASA) for root causes and future mitigations.

Mr. Jacobson earned an MS in Aeronautics and Astronautics from Purdue University in 2000 and a BS in Aeronautical Engineering from Embry-Riddle Aeronautical University in 1992.

Robert Joslin, PhD[1] – Chief Scientific and Technical Advisor (CSTA) for Flight Deck Technology Integration, FAA

Dr. Joslin joined the FAA in 2005. Prior to being selected in 2010 as the CSTA for Flight Deck Technology Integration, he served as an FAA flight test pilot with the Atlanta Aircraft Certification Office and the Fort Worth Special Certification Office, where he was involved in the certification of some of the latest flight deck systems. Dr. Joslin has served on various national/international committees developing regulations and certification standards for new technology with international experience living and working in aviation and aviation flight test centers worldwide. Dr. Joslin has over 60 published manuscripts in various aviation periodicals. Prior to joining the FAA, Dr. Joslin completed 30 years of military aviation service where he was a Colonel in the United States Marine Corps and a military experimental test pilot in jet, propeller, helicopter, and tilt-rotor aircraft at the Naval Air Test Centers in Patuxent River and

[1] Dr. Joslin is no longer employed by the FAA as of September 30, 2019

China Lake. Dr. Joslin was the Commander of Defense Contract Management Agency - Bell Helicopter, where he was responsible for the initial production, acceptance, and delivery of the V-22 tilt-rotor aircraft. He also was a Marine One pilot for the President of the United States under the Bush Sr. administration, a 1994 NASA astronaut candidate finalist, an Assistant Professor of Aerodynamics and Aviation Safety at the Naval Postgraduate School, and an Adjunct Assistant Professor with Embry-Riddle Aeronautical University.

Dr. Joslin received a PhD in Aviation from Embry Riddle Aeronautical University, an MS in Aeronautical Engineering from the Naval Postgraduate School, and a BS in Mechanical Engineering from the University of Florida. Dr. Joslin is a graduate of the U.S. Naval Test Pilot School and remains an active FAA flight test pilot, having flown over 100 aircraft types, with pilot ratings in over a dozen aircraft of all types.

Wayne Just – Aviation Safety Inspector in the Seattle Aircraft Evaluation Group (AEG), FAA

Mr. Just is an Aviation Safety Inspector in the Seattle AEG. At the Seattle AEG, Mr. Just is currently the Board Chair for the Flight Standard Board (FSB) and Flight Operations Evaluation Board (FOEB) on Dassault Falcon 7X, 8X, and Boeing B-747 airplanes. Prior to the Seattle AEG, Mr. Just was a front-line manager in a FAA Flight Standards District Office. His previous experience includes being inspector in charge at the EAA AirVenture Airshow in Oshkosh, WI. Mr. Just was also Principal Inspector for FAR 135 on-demand air carriers operating jet, turbo-prop and piston airplanes. As an FAA Flight Standards District Office inspector, Mr. Just conducted pilot certification duties and held responsibility for Oversight of Designated Pilot Examiners and Oversight of airshows, air races and aviation events (hot air balloon events, parachute activities, etc.).

Mr. Just's prior aviation industry experience includes positions as airline Vice President of Flight Operations, the Director of Flight Standards & Training, the Director of Flight Operations, a Line Pilot for B-717/DC-9/MD-80, a Captain for MD-80/B-717, and an Instructor and Check Airman for the MD-80.

Mr. Just has over 37 years of flight experience. He is an accomplished airline transport pilot. His type ratings include the A-350, B-727, B-747-4, BE-300, BE-1900, CE-500, DA-EASY, and DC-9. Mr. Just is also a certified flight instructor. His experience in flight training includes being the Program Manager of the International Ab Initio Flight Training Program, the Flight Manager for a FAR 141 Flight School, a classroom instructor and flight instructor for a FAR 141 flight school, an aerobatic flight instructor for a FAR 141 flight school, and a flight instructor for FAR Part 61.

Mr. Just received a bachelor's degree from the University of North Dakota in Grand Forks, ND.

Matt Kiefer – System Safety Engineer, United States Air Force

Mr. Kiefer currently works as a Technical Expert for Risk Management and Aviation Safety in the US Air Force Airworthiness Office. He is responsible for directing the risk assessment and management process within the airworthiness process for the Air Force. Prior to coming to the Airworthiness Office he worked as a Systems Safety Engineer overseeing the incorporation of system safety into the acquisition activities of the Agile Combat Support Directorate as he led a team of engineers applying system safety to varied programs and maintained a robust mishap prevention program.

Before working for the Air Force, Mr. Kiefer worked as a Navy civilian engineer for six years in the joint T-6 program office. As Navy Class Desk for the Beechcraft T-6 Texan II airplane, he assisted the program Chief Engineer in connecting the T-6 issues and problems to Navy engineering resources by interfacing with the engineering capability of the T-6 joint program office and Air Force resources, providing engineering support to Navy T-6 operators, and ensuring Navy engineering and test support for T-6 operations. He also currently serves as a Commander in the Navy Reserve where he is designated as an Aerospace Engineering Duty Officer and specializes in engineering analysis of aircraft battle damage.

At Snow Aviation International in Columbus, Ohio, Mr. Kiefer was a systems integration and flight test engineer, responsible for all flight test instrumentation and data acquisition on several flight test programs to test modifications to C-130 airplane. These programs included improving the short-field takeoff and landing performance of the C-130 and also demonstrating the launch and recovery of an Unmanned Aerial Vehicle (UAV) from a C-130 in flight. He was also responsible for the integration of various aircraft systems and modifications to the company’s test aircraft including electronically controlled propellers, brake anti-skid system, wing-tip tank fuel plumbing, and navigational equipment.

Mr. Kiefer has a private pilot’s license with an instrument rating. He has Level III certification (systems planning, research, development, and engineering) in DOD acquisition, and is a Level III subject matter expert on System Safety for Air Force Airworthiness.

Mr. Kiefer earned an MS in Engineering Systems from the Naval Postgraduate School, and his BS in Electronics Engineering Technology from DeVry University.

Janeen Adrion Kochan, PhD – Engineering Research Psychologist, Volpe National Transportation Systems Center, Pilot, Designated Pilot Examiner

Dr. Kochan serves as a subject matter expert and human factors scientist on topics of instrument flight procedures development and flight deck automation. She helps develop, validate, and test risk-based decision-making tools including event sequence diagrams and fault trees concerned with loss-of-control in-flight and aircraft component failures. As an FAA instructor pilot and Designated Pilot Examiner, Dr. Kochan trains and evaluates pilots at all levels of airman certification. She serves as an Adjunct Professor teaching system engineering and human factors graduate courses at Embry-Riddle Aeronautical University – Worldwide.

Dr. Kochan has over 30 years of extensive research and operational training on pilots’ reactions to unexpected events and loss-of-control in-flight. Her primary translational research interests include expertise, human and system resilience, human performance, decision making, stress, fatigue, automation, workload, resource management, unexpected events, and training. Her research work on flight deck alerting and checklists includes an in-depth human factors evaluation and analysis of transport aircraft alerting functions, characteristics, and implications for future systems' adaptation.

As a former Boeing 767 captain and human factors instructor for a major U.S. airline, Dr. Kochan developed the human factors program, taught crew resource management, and designed Line Oriented Flight Training (LOFT) sessions for each training cycle to include a series of runaway trim scenarios. She has over 22,000 hours of flying time in a variety of aircraft, with type ratings in the Boeing 767/757, DC 8, DC-9, YS-11, CV-LB30, and numerous corporate jets. In addition, she holds current and active Airframe and Powerplant (mechanic), Inspector Authorization, Flight Instructor, and FAA Designated Pilot Examiner privileges.

Dr. Kochan holds a PhD in Applied Experimental and Human Factors Psychology from the University of Central Florida in Orlando. She also holds an MS in Industrial and Systems Engineering and a BA in Pre-medicine and Psychology from the Ohio State University.

Brett E. Portwood – FAA Technical Specialist - Safety and Integration

Mr. Portwood has 30 years of experience in the FAA as a Technical Specialist for Safety and Integration. Mr. Portwood provides expertise to the FAA Aircraft Certification Service in the area of safety analysis in support of the technical evaluation of complex integrated avionics, electrical, and mechanical systems on modern transport aircraft, unmanned aircraft systems, electric vertical takeoff and landing urban air transports, general aviation aircraft, and rotorcraft.

Mr. Portwood has successfully promoted safety analysis concepts to industry, the FAA, and foreign authorities through numerous presentations, briefings, and training courses, including custom tailored safety courses for certification authorities in foreign countries.

In 2013, Mr. Portwood participated in the Boeing 787-8 Critical Systems Review Team (CSRT), which included reviewing the airplane's design, manufacture, and assembly. The CSRT used in-service and in-production issues to focus its review. The CSRT employed a safety-risk methodology to prioritize areas for review and made several recommendations to improve processes which are intended to reduce risk.

Mr. Portwood co-authored, along with other government and industry safety professionals, the System Safety Assessment industry standard for civil aircraft, Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4761, Guidelines and Methods of Performing the Safety Assessment Process on Civil Airborne Systems and Equipment.

Prior to joining the FAA, Mr. Portwood spent 10 years in industry performing fault and failure analysis of avionics systems for a wide range of aircraft. In addition, while participating in the Navy nuclear program, he performed fault/failure analysis on nuclear reactor monitoring systems. Mr. Portwood has published professional papers on trends in system safety assessment methods.

Mr. Portwood received a BS in Physics from San Diego State University.

Jerry Ramos – Senior Aerospace Engineer, Systems and Equipment Branch, Los Angeles Aircraft Certification Office (ACO) Branch, FAA

Mr. Ramos is a Senior Aerospace Engineer in the Systems and Equipment Branch, AIR-793, at the Los Angeles ACO Branch. He has been involved in certification efforts on various articles and equipment installations from cabin systems to complex flight deck avionics and electrical systems, including reviews of systems safety aspects as well as software and complex airborne electronic hardware certification. In his role as a senior engineer, he provides technical and procedural guidance, coaching and mentorship to section engineers (and FAA designees) and industry staff to achieve a successful certification program. He has assisted in leading efforts for successful appointments of Organization Designation Authorizations (ODAs) in AIR-793.

Mr. Ramos has advocated for and provided briefings on *The FAA and Industry Guide to Product Certification* to industry staff and within the FAA. He promotes a collaborative partnership between industry and the FAA including facilitating and moderating various challenging and difficult certification issues which require all stakeholders to be accountable and have a clear understanding of the regulatory requirements and their roles and responsibilities. He currently supports the B737 MAX Technical Advisory Board as the Technical Coordinator assisting the team lead.

Mr. Ramos' extensive experience in airplane system design and analysis, airworthiness certification (design and production), continued airworthiness, and repair station activities is a result of his over 25 years working in both industry and the FAA on various category aircraft.

Mr. Ramos received his BS in Electrical Engineering from Xavier University – Ateneo de Cagayan.

George Romanski – Chief Scientific and Technical Advisor (CSTA) for Aircraft Computer Software, FAA

Mr. Romanski is the FAA's CSTA for Aircraft Computer Software. Mr. Romanski is involved in developing rules, guidance, regulations, and technical standards to help industry and regulators maintain a safety framework for aircraft computer software. This involves encouraging collaboration between many stakeholders and embracing forward-looking initiatives to ensure that the development and certification processes become more efficient without compromising safety. At present, he is co-chairing a working group that is developing a streamlined approach to certification. Mr. Romanski knows that by anticipating and preparing for future needs, he can encourage industry and regulators to work in partnership, which benefits all who fly.

Mr. Romanski started his professional career as a graduate programmer in 1970. For the next 20 years, he developed compilers, run-time systems, and gradually moved to focus on real-time systems. In 1990, Mr. Romanski started work on safety critical systems and formed a team specializing in software certification for the aviation industries. In 1999, he co-founded Verocel, a company that developed tools and supports certification projects. As CEO, Mr. Romanski led the company to develop plans and procedures that were compliant with aviation needs and other standards to support different industries.

Recently, Mr. Romanski was involved in working groups that developed DO-178C and supplements, DO-248C, ARINC-653, and many others. Through his direct involvement on many certification projects, he has a wealth of experience in showing compliance with safety regulations.

Mr. Romanski received a BS in Computer Technology from Wolverhampton Polytechnic.

Jeffery A. Schroeder, PhD – Chief Scientific and Technical Advisor for Flight Simulation Systems, FAA

Dr. Jeffery Schroeder is the FAA's Chief Scientific and Technical Advisor for Flight Simulation Systems. His primary role for 10 years in that capacity has been providing the key engineering contributions to the FAA's rules and guidance for upset prevention and recovery training (UPRT). He has taught over 1,000 instructor pilots at airlines worldwide on UPRT. Previously, Dr. Schroeder worked at NASA for over 20 years in the disciplines of flight dynamics and control, human factors, rotorcraft, and air traffic management. His last position was Chief of the Aviation Systems Division. He has scores of technical publications in airplane upset training, flight control systems, flight simulation, and human factors. He has taught multiple courses in aircraft dynamics and control at Stanford and San Jose State University.

Dr. Schroeder received the Outstanding Aerospace Engineer Award from Purdue University. He is a Fellow of the Royal Aeronautical Society and an Associate Fellow of the American Institute of Aeronautics and Astronautics.

Dr. Schroeder has a PhD from Stanford and an MS and BS from Purdue, all in Aeronautics and Astronautics.

Addison P. Tower – Flight Test Pilot, FAA

Mr. Tower is currently a Flight Test Pilot for the FAA, where his work was instrumental in certification of the first single-engine small business jet. He currently is involved in certification projects for aircraft ranging from hot air balloons to human-carrying octocopters to the Boeing 747.

Mr. Tower served as a pilot in the Air Force for 24 years. He flew operationally for 1,280 hours in the Boeing B-52 and Rockwell (now Boeing) B-1. During his operational flying, he earned three Exceptionally Qualified ratings (top 1%) on Air Force check rides. As a B-1 Test Pilot, Mr. Tower performed performance, flying qualities, and extensive systems and weapons testing on upgrades to the B-1. As an Instructor Test Pilot at the Air Force Test Pilot School, he instructed 168 students in performance, flying qualities, and multiengine flight test techniques.

Mr. Tower has 4,400 flight hours in 70 aircraft types. He holds type ratings in 11 aircraft, including the Boeing 737 and Boeing 787. He is a certified flight instructor with instrument and multi-engine ratings, an airline transport pilot, and a commercial balloon pilot.

Mr. Tower holds a Master of Military Arts and Sciences from Air Command and Staff College. He earned BS degrees in Computer Science and Russian from the University of Wisconsin–Madison. He is a graduate of the United States Air Force Test Pilot School.

Troy A. Zwicke – Aircraft Evaluation Pilot – Operations Inspector and OJT Instructor, Long Beach Aircraft Evaluation Group (AEG), FAA

Mr. Zwicke is an Operations Aviation Safety Inspector and an on the job training (OJT) Inspector at the AEG.

Mr. Zwicke joined the FAA as a dual qualified operation inspector in General Aviation and Air Carrier Operations and has since fulfilled multiple roles, including Principal Operations Inspector (POI), Chair of several Flight Standardization Boards (FSB), Flight Operations Evaluation Boards (FOEB) and an Operations Inspector to the National Simulator Program (NSP).

Mr. Zwicke is currently the Chair of the FSB and FOEB on the following aircraft: Airbus A-220, Bombardier Challenger 600 series airplane, Bombardier Global 7500, Bombardier CL-215/215T/415 Water Bomber, Boeing 707/720/727, DC-8, Gulfstream V series, and the L-49 Constellation.

Mr. Zwicke has over 34 years of flight experience. He is an accomplished Airline Transport Pilot (ATP) with type ratings in the ATR-42, ATR-72, BA-3100, BD500, CE-750, CL-604, DC-8, DHC-6, DHC-6HG, EMB-500, EMB-505, EMB-550, G7500, G-V, LR-45 and LR-60. Mr. Zwicke also holds a Commercial Pilot Certificate for Light-Than-Air Balloon and Airship. Mr. Zwicke holds a Gold Seal Flight Instructor certificate, ground instructor certificate, flight engineer certificate and remote pilot certificate. Mr. Zwicke has completed the FAA 6-week Test Pilot Course in 2010 at the National Test Pilot School.

Mr. Zwicke received a Master’s Degree in Commercial Aviation from Delta State University in Cleveland, MS and a Bachelor of Science degree in General Business from Excelsior College in Albany, NY.

2. Evaluation of Redesign of the B737 MAX MCAS

The TAB evaluated efforts by Boeing associated with the redesign of the B737 MAX MCAS. These efforts informed the FAA's decision making on MCAS approval and return of the aircraft to service. The FAA's decisions to approve the MCAS design change, as well as to return the aircraft to service, are dependent on completion of the FAA's efforts through normal certification procedures conducted by the BASOO and Boeing.

The TAB evaluation was conducted independently from the BASOO certification process and prior to the completion of the BASOO certification data review activities. As such, any issues observed from the TAB evaluation are not based on BASOO certification processes but were based on the material presented to the TAB by Boeing from May 6, 2019 through October 19, 2020.

The TAB evaluated the MCAS design, procedural, and training mitigations at representative airspeeds and configurations while maneuvering throughout the normal, operational, and limit flight envelopes that could be simulated in the eCAB. The eCAB is a fixed base (static) device; hence, ambient noise, motion effects, and the full suite of cues typically available in a full flight simulator could not be evaluated. The manual trim wheel forces were not representative of the actual aircraft, so they were not evaluated. Boeing subsequently provided flight test data and analysis in Boeing Report, *737-8/-9 Stabilizer Trim Wheel Forces* to show that the manual trim wheel forces were acceptable.

The maneuvers, conditions, and configurations flown in the eCAB were those specified in Boeing Flight Test Plan, *737 MAX 8 Enhanced Digital Flight Control System (EDFCS) P12.1.1 Flight Control Computer (FCC) Software Certification Cab Test-S5.02.AAE*, augmented by other potential areas of interest, to include, but not limited to: spoiler deployment, V_{dive}, manual electric trim to high AOA, 5.4 degree AOA disagree, windshear and ground proximity warning system escape maneuvers.

Software version P12.1.2 was also evaluated in the eCAB which included, but not limited to, the Cross-FCC monitoring and the Near Stall enhancements.

2.1 Evaluation Scope

The evaluation of P12.1.1 included a review of Boeing's and Collins Aerospace's (one of the B737 MAX avionics providers) system development processes, including system safety assessment, system requirements validation and verification, and software development assurance. Additionally, the TAB's evaluation included specific design reviews of the MCAS lateral oscillation observed in the ET302 accident flight data, MCAS activation/re-synchronization update, MCAS AOA signal enhancements (split vane monitor and mid-value select [MVS] input), trim system, and MCAS maximum command limit.

The evaluation of P12.1.2 included the re-evaluation of the design enhancements above, as well as the new functionality in P12.1.2, which included the Cross-FCC monitoring, Near Stall Autopilot Enhancements, and Modified Maximum Trim Authority Functionality.

The TAB was asked to give their opinion on the pros and cons of a crewmember pulling a circuit breaker to silence an erroneous activation of a stick-shaker. The TAB's full opinion was provided to FAA management separately from this report. The essential issue is whether an erroneous stick-shaker activation interferes with the flightcrew's ability to safely operate the airplane. If pilot evaluations determine that an erroneous activation does interfere with safe operation, then a circuit breaker pull is appropriate. Otherwise, a circuit breaker pull is inappropriate, due to the possible unintended consequences. The TAB's recommendation was to make the circuit breaker pull decision on the basis of the documented hazard severity. The TAB also recommended any proposed circuit breaker pull procedure should undergo further evaluation to obtain ergonomic data and simulator test data needed to show compliance with all applicable regulations.

2.2 Design Evaluation

The design evaluation included assessments of the systems engineering, system safety, software, flight controls and flight deck interface, and stabilizer trim cutout switches. The assessments included a discussion of each topic, and any identified issue(s) and action item(s) or conclusion(s).

2.2.1 Systems Engineering Assessment

The Boeing requirements validation process was evaluated taking into account the overall aircraft operating environment and functions. This included validation of requirements and verification of the design implementation for certification and product assurance. Requirements validation was documented in Dynamic Object Oriented Requirements System following the intent of SAE Aerospace Recommended Practice (ARP) 4754 *Guidelines for Development of Civil Aircraft and Systems* process for development assurance.

Discussion: Boeing's validation and verification processes meet the intent of Title 14 of the Code of Federal Regulations 14 CFR 25.1309 for the high-level requirements that the TAB reviewed. However, the TAB is aware of Boeing document, *Boeing Commercial Airplanes (BCA) Development Assurance Plan for Type Design Changes*, which identifies all of the development assurance activities that take place when implementing production type design changes to BCA development assurance program airplanes after the initial Type Certificate (TC) or Amended Type Certificate (ATC) has been issued. The TAB has determined it would be prudent, as an extension of the TAB review, to have the BASOO perform an audit of this development assurance plan.

> **Action Item 1**: As an extension of the TAB review, complete an audit of Boeing's development assurance process as documented in their development assurance plan.
>
> **Resolution**: Action item closed. Audit completed. The TAB evaluated and accepted the Development Assurance Accomplishment Summary document.

2.2.2 System Safety Assessment

The TAB reviewed Boeing's integrated aircraft-level system safety assessment (iSSA), Enhanced Digital Flight Control System (EDFCS), Autothrottle, And Yaw Damper Safety Analysis, and the Electrical Wire Interconnection System (EWIS) – System Safety Assessment. These analyses assessed the integration aspects of the MCAS FCC and trim system.

Issue 1: The Boeing integrated aircraft-level SSA did not formally consider the functional integration of the spoiler system with the trim system and MCAS. For example, there was no analysis of combinational failures of the trim system, FCCs and spoiler system failures, and the effect on longitudinal control of the aircraft.

Discussion: The integrated aircraft-level SSA should address the functional integration of system functions. Loss or malfunction of longitudinal control should include an analysis of those systems that are functionally integrated that contribute to that aircraft-level function. Boeing did address the functional integration of the trim system and the FCC MCAS at the aircraft level. However, there was no formal analysis that included the functional integration of the spoiler system. Boeing indicated they do have company data showing the aerodynamic effects of the spoiler system in relation to the trim system and MCAS, but it was not submitted as compliance data. Boeing also indicated that they assessed the effects of spoiler failures in combination with trim and MCAS failures as part of their single and multiple failure analysis assessment. This information is included as compliance data in the integrated aircraft-level SSA. The TAB reviewed the single and multiple failure analysis to assess whether the effects of spoiler system failures, in combination with trim system and MCAS FCC failures, were evaluated.

> **Action Item 2**: Boeing should submit further analysis and test data to ensure proper functional integration of the spoiler system with the trim system and MCAS to include a top down assessment, or equivalent, which verifies the bottom up S&MF analysis adequately covered combinations of speed trim system and spoiler system failures not shown to be extremely improbable.
>
> **Resolution**: Action item closed. Based on TAB review of the Boeing closeout memorandum and associated reference documents. Discussion in a meeting between Boeing and the TAB on September 23, 2019 led to the creation of a document to explain how Boeing's Airplane Functional Hazard Assessment AFHA and System Functional Hazard Assessments (SFHAs) for the B737 MAX work together to form a robust top-down analysis for airplane and system-level functions, and how that top-down analysis is verified by the bottom-up S&MF analysis. The TAB evaluated and accepted the analysis.

Issue 2: Review of Boeing fault trees for the MCAS showed inconsistently developed event probabilities.

Discussion: Upon further discussion with Boeing, the TAB noted that Boeing was still making edits to the fault trees and that the analysis was submitted to the BASOO as a courtesy in draft form. The final version of the analysis will be submitted at a future date.

> **Action Item 3**: Boeing should submit the final version of the MCAS fault trees.
>
> **Resolution**: Action item closed. Boeing provided the final version of the iSSA dated August 25, 2020, which was accepted by the TAB.

Issue 3: Boeing and Collins Aerospace have had two design escapes that have not been analyzed for root cause. One was a design error for the Auto Stab Trim Monitor in the fault tree for the Low Altitude Stabilizer Runaway failure condition. The other was a requirements issue that resulted in the presence of an AOA Disagree message being tied to the AOA Indicator option on the primary flight display (PFD) instead of the monitor always being functional regardless of the AOA display option.

Discussion: Without a root cause, it is not clear whether other similar design escapes are present in the current MCAS design.

> **Action Item 4**: Boeing should submit the complete root cause analysis for the Auto Stabilizer Trim Monitor error in the fault tree for the Low Altitude Stabilizer Runaway failure condition (design escape).
>
> **Resolution**: Action item closed. Boeing provided close out coordination sheet, June 19 2019 that references the root cause analysis. The TAB reviewed and accepted the root cause analysis.
>
> **Future Action Item 1**: Boeing should provide the root cause analysis for why implementation of the AOA DISAGREE message did not meet the design requirements (i.e., presence was attached AOA Indicator option).
>
> **Resolution**: Action item closed. Boeing provided close out coordination sheet, dated November 5, 2019 which references the root cause analysis. The TAB reviewed and accepted the root cause analysis.

2.2.3 Software Assessment

The TAB evaluated the Software Certification Data Package in May 2019. The conclusions at that time were as follows:

> The processes used by the companies are consistent with expectations of DO-178B acceptable means of compliance. The artifacts reviewed provided a high level of confidence that the software implements the required behavior, and assurance that no additional unsafe functionality has been introduced. The TAB had no software development process related findings.

The reviews of the software data package assumed that the system level requirements were complete and final. Upon a more detailed safety analysis, and design scrutiny, the system was modified to address some concerns.

The software development process was modified to include Issue Paper (IP) item SW-8a. Effectively, this meant treating the design and verification using a model-based approach. The system requirements allocated to software were initially expressed using a system modelling language and supplied to Collins. Collins would use these models to add appropriate detail so chat code could be developed from them. They were classified as low-level requirements.

The requirements processes were separated in two, with the system diagrams now managed by Boeing for both development and verification, and these were then handed to Collins for further refinement to low-level software requirements. In addition, Boeing developed a set of requirements at a higher level of abstraction and then showed that these requirements now traced to the system diagrams, as required by IP item SW-8a.

This resulted in new process description documents to describe the capture, review, and verification of these requirements performed by Boeing. It also required an update to the Plan for Software Aspects of Certification (PSAC) and other planning documents at Collins to describe the activities and objectives that Collins was responsible for. An appendix was added to the PSAC to describe the details and provide appropriate checklists that could be used to show compliance.

These changes were the subject of many Stage of Involvement audits (SOI#1, SOI#2, SOI#3, and SOI#4). The audits were performed by a team comprised of FAA (BASOO and other offices), EASA, and TCCA. The SOIs raised findings and issues that needed to be resolved. The findings of each audit were resolved before the next audit would take place.

The software process activities were performed to satisfy (Design Assurance Level) DAL-A objectives using the Collins Aerospace PSAC. The document provides an overview of the FCC system and the software. It describes the certification basis and the software levels. The Boeing System Safety Assessment (SSA) processes consider the likelihood and severity of failure events. These processes are then used to classify the rigor required for development and verification.

The PSAC outlines how compliance with the certification requirements is to be established. The PSAC and other process documents were revised and reviewed a number of times until the approach to the software development and verification was agreed by the team of auditors.

On the software side, the processes and procedures were changed to add clarity, but verification activities performed were largely unchanged. The software was found to implement the requirements faithfully.

The System Safety Assessment processes updated at Boeing resulted in a number of design changes to add levels of cross-checking and redundancy. The system level requirements were modified and fed to the Collins software processes. The software processes were followed and software modified and verified in accordance with the agreed procedures.

The audit meetings were coordinated by the BASOO organization, and they captured and tracked the resolutions to all action items.

The final SOI#4 was held and the Software Accomplishment Summary (SAS) document was reviewed.

The SAS provides an analysis of the successful completion of the development and verification. The review team considered the SAS and all of the documents that are referenced out and concurred with its compliance statement. The TAB concluded that the software implements the system requirements as stated in the Boeing requirements repository and extracted to the configuration index document.

Some problems were not fully closed but they were classified as not posing a safety risk. These problems were left as improvements to be addressed on future aircraft updates. The TAB assessed the list of deferred problems and agreed to leave them in that category.

Conclusions: The software was updated to add new functionality, and correct some system-level requirements. The changes to the software were also developed to an increased level of assurance rigor as established by the System Safety Analysis. The processes used by Collins Aerospace are consistent with the expectations of DO-178B acceptable means of compliance. The artifacts reviewed provided a high level of confidence that the software implements the required behavior as documented in the system requirements allocated to software, and assurance that no additional unsafe functionality has been introduced.

2.2.4 Flight Controls and Flight Deck Interface Assessment

Issue 1: Boeing concluded during the design phase that multiple rapidly successive MCAS events, when dwelling in the high AOA region, are no more hazardous than a single MCAS event, since it was assumed the pilot would use the electric trim to completely counteract any out-of-trim forces. Boeing engineers and test pilots "discussed the scenario of repeated unintended MCAS activation during MAX development and deemed it no worse than single unintended MCAS activation."

Discussion: The preliminary accident reports indicate that pilot workload was adversely affected by the multiple rapidly successive MCAS events (five seconds after every manual trim input) when dwelling in the erroneously sensed high AOA region, even after applying electric trim. During TAB pilot evaluations of the flight condition, considerable attention and repetitive actuation of the electric trim by the pilot at the controls was required to maintain pitch control of the aircraft. The MCAS design change will only allow one MCAS event when the aircraft indicates (either correctly or erroneously) that it is dwelling in the high AOA region. The MCAS will reset itself once the aircraft leaves the high AOA region.

> **Conclusions**: The TAB evaluated P12.1.2 and accepts that the proposed design change is a safe and compliant mitigation.

Issue 2: AOA DISAGREE message in HUD.

Discussion: The HUD installed in the eCAB did not include the AOA DISAGREE message (amber caution) (see Figure 1) that was made a non-optional display feature in the Head Down Display (HDD) primary flight display as part of Software Blockpoint 1.5. (Note: Boeing has stated that a HUD on the pilot side (left side) is installed via STC #ST02522SE by a third party, however, it is installed in the factory by Boeing.)

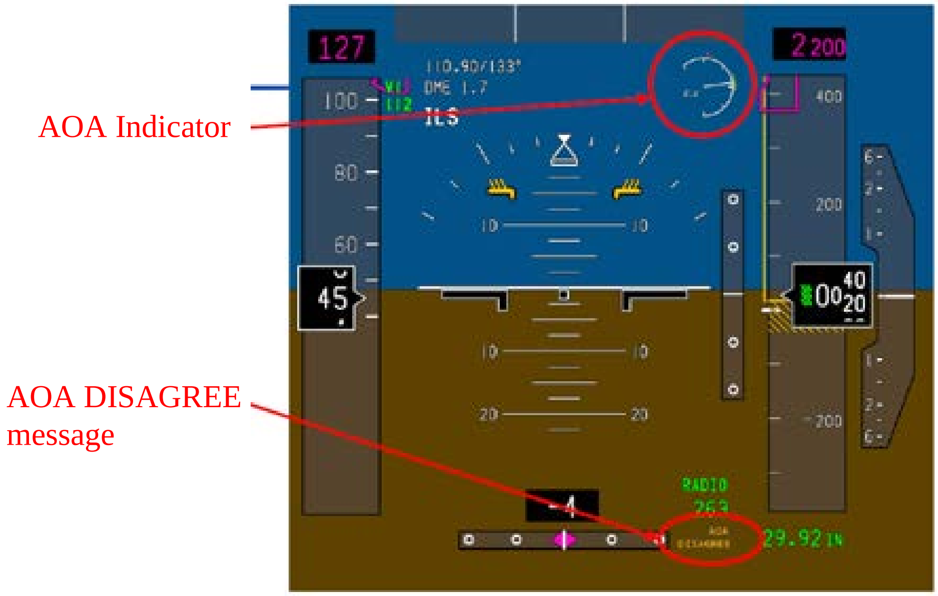


Figure 1. B737 MAX Primary Flight Display

The guidance in Advisory Circular (AC) 25-11B, *Electronic Flight Displays* states the following:

> F.5.1.1 General. If the content, arrangement, or format of the HUD is dissimilar to the HDD, it can lead to flightcrew confusion, misinterpretation, and excessive cognitive workload. During transitions between the HUD and HDDs (whether required by navigation duties, failure conditions, unusual airplane attitudes, or other reasons), dissimilarities could make it more difficult for the flightcrew to manually control the airplane or to monitor the automatic flight control system. Dissimilarities could also delay the accomplishment of time-critical tasks. Some differences may be unavoidable, such as the use of color on the HDD and a single color (i.e., monochrome) on the HUD.
>
> F.5.1.3 Guidelines for HUD-HDD Display Compatibility.
>
> F.5.1.3.1 Consistent Displays and Format. The content, arrangement, symbology, and format of the information on the HUD should be sufficiently compatible with the HDDs to preclude pilot confusion, misinterpretation, increased cognitive workload, or flightcrew error. (See paragraphs 5.3 and 5.6 of this AC.) The layout and arrangement HUD and HDD formats of the same information need to convey the same intended meanings. (See paragraph 6.2 of this AC.) For example, the relative locations of barometric altitude, airspeed, and attitude should be similar. Likewise, the acronyms and relative locations of flight guidance

mode annunciations for thrust and lateral and vertical flight path should be similar.

Future Action Item 2: SACO should work with the HUD STC holder to add the requirement for the B737 MAX HUD STC to include the AOA DISAGREE message.

Resolution: Action Item closed: SACO confirmed STC design change during B737-10 certification. Retroactive incorporation will be based on SACO Corrective Action Review Board (CARB) process.

Issue 3: Examination of AOA inputs to the lateral directional controls.

Discussion: There was concern that invalid AOA values may adversely impact other flight control functions. For example, according to the ET302 preliminary accident investigation report, the left AOA vane showed a value of 74.5 degrees after takeoff. The report also states:

> Six seconds after the autopilot engagement, there were small amplitude roll oscillations accompanied by lateral acceleration, rudder oscillations and slight heading changes. These oscillations continued also after the autopilot was disengaged.

These oscillations were not noted in the text of the Lion Air preliminary accident investigation report and lateral directional data traces also did not appear in the report. This caused the TAB to consider what safety impacts a faulty AOA sensor may have on other parts of the control system, such as control feedback, gain scheduling, or mode changes. A Boeing flight control engineer that specializes in lateral directional control presented data to the TAB to address these concerns.

Boeing presented the yaw damper stability analysis data for two cases. First, normal operation of the B737 MAX at low and high AOA, and second, similar stability analysis with one AOA vane showing a high sensor bias. In both cases, the data showed stability margins sufficient for safe flight.

Conclusions: The designed AOA inputs to the lateral directional controls are safe and compliant.

Issue 4: Boeing has developed several changes for the MCAS control logic governing the system activation, AOA data monitoring, and maximum command limit.

Discussion: In both the JT610 and ET302 preliminary accident investigation reports, inadvertent MCAS activation appears to have caused an excessively high workload for the flightcrews and appears to have been a contributing factor in both accidents. Although the aircraft is equipped with two independent sensors, the inadvertent activation was the result of erroneous data from a single faulty AOA sensor being used. In the existing B737 MAX FCC control logic for MCAS, one AOA signal is monitored at a time and calculations are made from that AOA signal to determine whether to add MCAS trim and by how much. The changes Boeing has developed to address this in the control software will provide three new protections. The first change is a new AOA monitoring logic that will perform a comparison between the two AOA sensors and deactivate MCAS and speed trim if there is disagreement over the 5.5-degree trigger threshold. AOA sensor selection logic also includes a mid-value select (MVS) AOA source selection input to MCAS function. Since there are only two AOA vanes, and three inputs are needed for an MVS function, this MVS approach selects the middle value of: the left AOA vane, the right AOA vane,and the previous MVS output. Both flight control computers will use the MVS selected output rather than their own local AOA vane value. These changes mitigate failures related to the AOA vane that would cause inadvertent MCAS activation. Second, MCAS will be limited to a maximum trim input not to exceed the maximum amount allowed by the MCAS trim tables for a given Mach. This limit includes any manual trim the pilot may apply during an MCAS event and prevents compounding manual trim with the MCAS trim inputs. The maximum trim input during an MCAS activation is set to ensure that the stab trim does not overpower the elevator by safely limiting the authority of MCAS. Third, a change was made in how pitch trim is resynchronized during and after an MCAS event. Normally during an MCAS event, pitch trim will be returned to the pitch trim setting that was set when MCAS engaged. With the new change, the FCC will account for any manual trim that either pilot may select during an MCAS event and only return to the newly selected trim setting at the end of that MCAS event. The resynchronization changes will also prevent more than one application of MCAS trim from being applied during an MCAS event. These changes will prevent erroneous and multiple applications of MCAS trim and prevent excessively high workload for the crew which contributed to the two B737 Max accidents.

Conclusions: The TAB accepts that the P12.1.2 MCAS control logic changes for AOA and MCAS control are safe and compliant.

2.2.5 Stabilizer Trim Cutout Switches Assessment

Issue 1: The B737 MAX speed trim system (speed trim function and MCAS function), cannot be disabled without also disabling all other electric (autopilot or manual trim switch on control yoke) stabilizer trim inputs. However, the B737 NG models have a switch control that would disable speed trim (through inhibiting the autopilot stabilizer trim) while allowing for manual electric trim to remain active.

Discussion: The TAB evaluated the function of the stabilizer trim cutout switches on the control stand, which were changed on the B737 MAX (from the B737 NG). The stabilizer trim cutout switches on the B737 MAX disrupt power to the stabilizer trim motor instead of isolating the main electric trim and autopilot trim inputs to the motor. The TAB has reviewed this change on the MAX and has determined that the current emergency procedures, coupled with the changes to MCAS, will be sufficient in mitigating MCAS anomalies related to automatic pitch trim. Having separate cutout switches for the main electric trim and autopilot trim inputs to the motor would serve no purpose with the current checklist procedures. Even if the possibility exists to isolate such systems, the use of such techniques in flight that are outside of the published procedures are discouraged, since the wrong action could make matters worse.

Conclusions: The stabilizer cutout switches on the B737 MAX control stand provide proper means to disable pitch trim in accordance with emergency procedures. They are safe and compliant with the certification basis. The TAB recommends no further research or changes to the stabilizer trim cutout switches.

2.2.6 CPU and Memory Catastrophic Failures

Issue: Simulated CPU and memory failures demonstrated in the eCAB during BASOO certification activity were intended to address two very remote, but possible, postulated hardware failures in the FCC CPU and memory that resulted in nose-down stabilizer movement that was deemed to be unacceptable by the BASOO.

Discussion: Boeing in discussions with the BASOO has since reclassified the hardware failures as catastrophic failure conditions. Boeing is adding cross-FCC software monitoring to mitigate these single point failures.

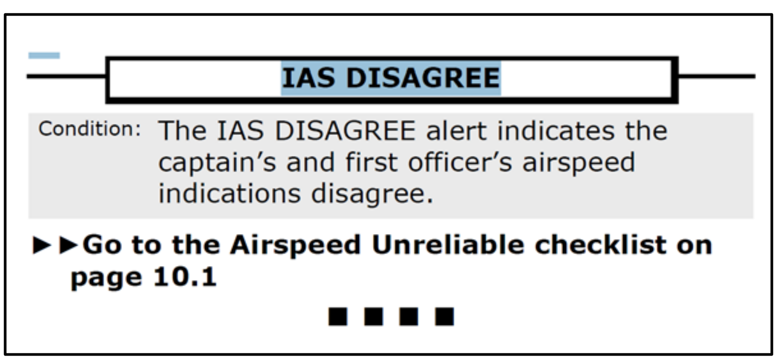
Action Item 5: Boeing should address the FCC CPU and memory postulated failure issue discovered during eCAB certification testing.

Resolution: Action item closed. The TAB evaluated new monitors to detect failures in P12.1.2 and evaluated thresholds by conducting eCAB testing. Boeing provided iSSA with monitor coverage dated August 25, 2020. The TAB evaluated and accepted the iSSA.

2.3 Procedures Evaluation

The TAB evaluated procedures by looking at multiple issues and providing action item(s) and conclusion(s).

Issue 1: The single step in the QRH procedure for IAS DISAGREE (Caution-Amber message) directs the pilot to the AIRSPEED UNRELIABLE checklist in the unannunciated section of the QRH, which then has multiple memory items (i.e., immediate action steps), as shown in Figures 2 and 3.


IAS DISAGREE

Condition: The IAS DISAGREE alert indicates the captain's and first officer's airspeed indications disagree.

►►**Go to the Airspeed Unreliable checklist on page 10.1**

■ ■ ■ ■

Figure 2. B737 Quick Reference Handbook – IAS DISAGREE Procedure

Airspeed Unreliable

Condition: Airspeed or Mach indications are suspected to be unreliable. (Items which might indicate unreliable airspeed are listed in the Additional Information section.)

Objective: To identify a reliable airspeed indication, if possible, or to continue the flight using the Flight With Unreliable Airspeed table in the Performance Inflight chapter.

1 Autopilot (if engaged) . . . . .Disengage

2 Autothrottle (if engaged). . . . . .Disengage

3 F/D switches (both) . . . . OFF

4 Set the following gear up pitch attitude and thrust:

Flaps extended . . . . 10° and 80% N1

Flaps up . . . . 4° and 75% N1

Figure 3. B737 Quick Reference Handbook – Airspeed Unreliable Procedure

Discussion: Emergency Procedures that require immediate awareness and immediate action are classified as Warning (Red) level alerts in accordance with both the current amendment level (25-131) of 14 CFR 25.1322 Revised as of January 3, 2011 and the Additional Design Requirements stated in *Boeing Commercial Airplanes Model 737-8, PS12-0038 G-1 Issue Paper Appendix E (page E-26).*

For example, the AOA provides a static pressure correction input for the IAS and ALT, hence the observed condition is that the IAS DISAGREE and the ALT DISAGREE may both illuminate when there is an impending AOA DISAGREE. There is no prioritization of the IAS DISAGREE and the ALT DISAGREE since they are both amber Caution level messages displayed on the PFD. However, the QRH procedure for ALT DISAGREE is to check barometric altimeter settings, while the IAS DISAGREE directs the pilot to the Airspeed Unreliable Checklist that has immediate action steps.

As changes to these checklists have developed, Boeing has proposed to make the AOA DISAGREE checklist to be exactly the same as the IAS DISAGREE checklist, i.e., it directs the pilot to the AIRSPEED UNRELIABLE checklist in the unannunciated section of the QRH. For the same reasons stated above for IAS DISAGREE, the AOA DISAGREE alert now effectively has memory items, and the alert should be prioritized appropriately.

> **Future Action Item 3**: Boeing should prioritize the IAS DISAGREE and AOA DISAGREE alerts appropriately. This will assist the pilots in prioritizing their actions in the high-workload environment that could result from an AOA DISAGREE, such as during takeoff, climb-out, approach and landing.

Resolution: Action item open. Requires a Boeing commitment for a longer-term solution.

Issue 2: Speed trim system vs. speed trim function vs. MCAS terminology.

Discussion: The B737 MAX speed trim system in the enhanced design is comprised of a speed trim function and an MCAS function, whereas the current B737 NG speed trim system design only has a speed trim function. Failures of either or both speed trim system functions in the new design will illuminate the SPEED TRIM FAIL (amber) light in the overhead panel; however, the QRH procedure only states that the speed trim system has failed. It is important to clarify that the speed trim system encompasses both the legacy speed trim function and the MCAS function.

Action Item 6: Boeing should ensure the SPEED TRIM FAIL procedure in the QRH encompasses both the speed trim function and the MCAS function.

Resolution: Action item closed. Boeing has incorporated changes in the Boeing QRH. The TAB has evaluated the changes to the Boeing QRH and found them acceptable.

Issue 3: Incomplete QRH procedures for runaway stabilizer.

Discussion: The ET302 preliminary accident investigation report stated that the first officer asked if he could try the trim manually and, when the captain told him to try, stated that it is not working. The QRH procedures for Stabilizer Trim Inoperative include notes stating that manual forces may be high and may require two pilots to operate the trim wheel, however the QRH procedures for Runaway Stabilizer do not include those same notes.

Future Action Item 4: Boeing should add the notes from the QRH Stabilizer Trim Inoperative procedure to the Runaway Stabilizer procedure.

Resolution: Action item closed. Boeing has incorporated changes in the Boeing QRH. The TAB has evaluated the changes to the Boeing QRH and found them acceptable.

Issue 4: AOA DISAGREE message is possible evidence of an AIRSPEED UNRELIABLE condition but is not listed in the QRH.

Discussion: The AOA DISAGREE message in the enhanced design may illuminate when airspeed is observed to be unreliable; however, it is not listed in the QRH as possible evidence of an airspeed unreliable condition.

Action Item 7: Boeing should add AOA DISAGREE to the list of additional information as possible evidence of an AIRSPEED UNRELIABLE condition in the QRH.

Resolution: Action item closed. Boeing has incorporated changes in the Boeing QRH. The TAB has evaluated the changes to the Boeing QRH and found them acceptable.

Issue 5: Manual trim crank/hand wheel control forces.

Discussion: The ET302 preliminary accident investigation report included a statement by the first officer that suggested the manual trim was not working. The design is supposed to allow manual trim wheel operation by the pilots when in this flight/system condition, albeit with high aerodynamic loads reflected back to the trim wheel. The TAB was unable to evaluate the manual control crank/hand wheel forces in the eCAB, since they were not representative of the aircraft. It is anticipated that the B737 MAX FFS will have manual trim crank/hand wheel forces that are satisfactory for training pilots to use manual trim. Consequently, the TAB asked Boeing to provide the manual trim wheel force information that they had gathered, which indicated forces in excess of 50 pounds in the normal and operational envelopes of the aircraft. There is currently no FAA regulation or guidance that specifies maximum trim crank/hand wheel forces, other than the qualitative statement in 14 CFR 25.143 (b) that pilot actions for controllability and maneuverability shall not require exceptional piloting skill, alertness, or strength.

Future Action Item 5: The BASOO, the FAA's AEG, or both should evaluate the manual trim wheel control forces in the B737 MAX FFS to determine if exceptional pilot strength, alertness, or skill is required for controllability and maneuverability of the aircraft.

Resolution: Action item closed. Boeing provided and TAB reviewed/accepted Boeing Report, *737-8/-9 Stabilizer Trim Wheel Forces* to verify exceptional pilot strength, alertness, or skill is not required for controllability and maneuverability within the certificated envelope of the aircraft.

Issue 6: IAS DISAGREE and AOA DISAGREE in QRH

Discussion: As Boeing has made changes to the checklists during the return to flight process, in coordination with the large number of stakeholders involved with the process, they have changed the AOA DISAGREE checklist to be exactly the same as the IAS DISAGREE checklist, i.e., it directs the pilot to the Airspeed Unreliable checklist in the unannunciated section of the QRH. The Airspeed Unreliable checklist has several memory items. There are now two checklists (IAS DISAGREE and AOA DISAGREE) that technically do not have memory items, but refer directly to a checklist that does have memory items. In all three situations (the pilots have determined the airspeed is unreliable, an IAS DISAGREE alert, and an AOA DISAGREE alert), the overall goal is for the flightcrew to execute the Airspeed Unreliable memory items immediately. The TAB believes that the cleanest way to do this is to retitle the Airspeed Unreliable checklist to include the other two situations, thus: Airspeed Unreliable or IAS DISAGREE or AOA DISAGREE. The Boeing 747 QRH is structured as we are suggesting; there is a checklist titled Airspeed Unreliable or IAS DISAGREE that has memory items.

Action Item 8: AEG to discuss with CMT and other stakeholders to consider incorporating IAS DISAGREE and AOA DISAGREE into Airspeed Unreliable Checklist so that it is titled Airspeed Unreliable or IAS DISAGREE or AOA DISAGREE, similar to the B747 checklist.

Resolution: Action item closed. The TAB concluded that with the enhanced training package, pilots will be able to successfully complete the separate IAS DISAGREE and AOA DISAGREE NNCs. This was also validated in the JOEB activity and supported by B737NG service history. The TAB observes that there is a potential for confusion and misunderstanding when QRHs (or other documents) constructed by individual CAAs or operators differ from the AFM. The TAB observes that guidance on this subject in AC 25.1581-1 conflicts with the rules in 14 CFR 25.1581 through 25.1587, and that clearing up this conflict would improve oversight and reduce confusion.

Issue 7: Stabilizer Trim Inoperative in QRH - Boeing to add step (if necessary) autothrottle disengage in QRH

Discussion: The proposed revision to the Stabilizer Trim Inoperative checklist in the QRH has a step to disengage the autopilot, but there is not a step to disengage the autothrottle. All other checklists that direct disengagement of the autopilot also direct disengagement of the autothrottle. For the sake of harmonization, this checklist should also include a step directing disengagement of the autothrottle.

Future Action Item 6: Boeing to add step (if necessary) Autothrottle Disengage in Stabilizer Trim Inoperative checklist in QRH.

Resolution: Action item open. Boeing should evaluate this issue further via normal process post RTS to determine if adding a step about autothrottle usage is warranted.

2.4 Training Evaluations

The TAB evaluated training procedures, materials, and requirements. The TAB noted five issues: level and type of pilot training, flightcrew interactions reasonably expected, deficiencies in trim system training, manual trim wheel forces, and the Flight Standardization Board (FSB) report. Each issue has an associated action item.

Issue 1: Determination of appropriate level and type of pilot training required for redesign of MCAS.

Discussion: In conjunction with the flight procedures evaluation, the TAB evaluated the MCAS training and checking requirements for adequacy. The TAB agreed that the Flight Standardization Board (FSB) determination of Level B Computer-Based Training (CBT) training was appropriate. The TAB also agreed that the FSB determination of Level B checking is appropriate.

AC 120-53B, *Guidance for Conducting and Use of Flight Standardization Board Evaluations*, Change 1, defines Level B training as aided instruction that can utilize audiovisual presentations, computer-based tutorial instruction, or stand-up lectures. Level B training does not require the use of part task trainers, flight training devices or full flight simulators. Level B checking is accomplished via oral or written exam, which can be accomplished via a tutorial computer-based testing method.

> **Action Item 9**: Boeing should submit the final version of Level B training (i.e., computer-based training) to the TAB for review.
>
> **Resolution**: Action item closed. TAB reviewed all level B training and Boeing incorporated appropriate changes to the level B training as documented in the FSB report. The TAB acknowledges that FSB report Appendix 7 requires a one-time full flight simulator training profile. The TAB reviewed that one-time simulator training and found it acceptable.

Issue 2: Boeing assumptions regarding compliance to 14 CFR 25.1302 for the kinds of flightcrew interactions with the equipment that can be reasonably expected in service by qualified crewmembers trained in their use.

Discussion: The TAB could not verify the initial and recurrent training requirements for pilots of worldwide air carriers, and hence could not comment on what pilot interaction could be reasonably expected in service by qualified crew members for worldwide air carriers.

Assumptions were made regarding 14 CFR 25.1302, in that:

> systems and installed equipment, individually, and in combination with other such systems and equipment, are designed so that *qualified flightcrew members trained in their use can safely perform* all of the tasks associated with the systems' and equipment's intended functions.

Although the TAB cannot comment on expected pilot interaction for worldwide air carriers, we note in the following paragraphs, regarding the assumption of *qualified flightcrew members* and pilot competencies.

The general reliability of installed equipment and the improved resiliency of the aviation system prevent most opportunities for pilots to practice dealing with novel, infrequent, ill-defined, or unexpected events. Past generations of pilots may have acquired more resilient behaviors due to the unpredictability of their equipment and environment (e.g., lack of reliable radar and not having our modern weather services may have led to experience in dealing with unforecast or unpredictable weather, or mechanical failures that were more frequent). Today's generation of pilots are generally not afforded many such experiential learning situations and spend much less time in experience building positions such as solo flight, flight instructing, and co-piloting than their predecessors.

Thus, for assumptions surrounding *qualified flightcrew members* to remain valid, there should be consideration for the changing nature of pilots, pilot training, and the environment. While training particular skills such as how to trim the aircraft is necessary, it may not be sufficient for the complexity of modern aviation and aerospace. In that respect, training on concepts associated with pilot resilience (decision-making, metacognitive skills, cognitive flexibility, adaptive expertise, etc.) combined with mentorship training as in 14 CFR 121.429 (Pilots in command: Leadership and command and mentoring training) may foster the airmanship needed in tomorrow's world. Consideration for training future generations of pilots should include specific focus on pilot resilience to ensure their best performance when faced with the next novel, infrequent, ill-defined, or unexpected event.

> **Future Action Item 7**: ICAO and CAAs should analyze the initial, recurrent, transition, and upgrade training needed to provide the proficiency and currency requirements for air carriers. They should identify the kinds of flightcrew interactions with the equipment that can be reasonably expected in service by qualified flightcrew members trained in their use.
>
> **Resolution**: Action item open. FAA should develop an action plan to engage ICAO and CAAs.

Issue 3: Evidence presented in the preliminary JT610 and ET302 accident reports suggests deficiencies in both flightcrews' trim system understanding, awareness, and use. These deficiencies may not have been individual, but may have been due to their respective airline training programs.

Discussion: SSAs, such as those performed by Boeing for the MCAS, estimate the likelihood of a flightcrew's improper management of trim system anomalies. Prior to the two accidents, Boeing's estimate of this occurrence may have been reasonable, as judged from witnessing the events in simulation. However, after the two accidents, it appears that the estimate was optimistic.

Although analysis of the MCAS design changes concludes that future MCAS failures will not result in adverse trim system conditions, the underlying assumptions of pilot trim competency raises potential weaknesses in today's training programs, which may be broader than the B737. These potential weaknesses are consistent with other incident and accident evidence of trim mismanagement in B737 airplanes and other aircraft. As the FAA has broad authority to require special emphasis training by 14 CFR Part 121 operators, and considering that trim awareness and use is a training item consistent with extended envelope training that began in March 2019, the recommendation below merely provides focus to existing training programs.

> **Future Action Item 8**: At the earliest regular training event, pilots of all B737 series airplanes should receive special emphasis training on trim system understanding, awareness, and use. Consideration should be given to broadening this training recommendation to pilots of all transport category airplanes.
>
> **Resolution:** Action item open. TAB reviewed and accepted special emphasis training on trim system understanding, awareness, and use on the B737 series airplanes as documented in the FSB report. FAA to follow-up to determine if special emphasis training should be given to all transport airplanes types and, if so, establish the necessary communications via inspector guidance during training program approval.

Issue 4: Manual trim wheel control forces.

Discussion: The ET302 preliminary accident investigation report suggested that the first officer could not manually trim the aircraft when the captain told him to try it. However, the design is supposed to allow manual trim wheel operation by the pilots when in this flight/system condition, albeit with high aerodynamic loads reflected back to the trim wheel. The TAB was unable to evaluate the manual control wheel forces in the eCAB, since they were not representative of the aircraft. It is anticipated that the B737 MAX FFS will have manual trim wheel forces that are representative of the aircraft. Consequently, the TAB asked Boeing to provide the manual trim wheel force information that they had gathered, which indicated forces in excess of 50 pounds in the normal and operational envelopes of the aircraft.

> **Action Item 10**: AEG should identify if special emphasis training for B737 series trim wheel forces awareness (including manual trim force requirement) is appropriate.
>
> **Resolution**: Action item closed. Boeing provided and the TAB accepted Boeing Report, *737-8/-9 Stabilizer Trim Wheel Forces*, and trim awareness training per FSB report.

Issue 5: Flight Standardization Board Report (FSBR), Revision 17, draft, added MCAS to the differences from base aircraft table. The table entry appears to list the MCAS as a function of STABILIZER TRIM.

Discussion: MCAS is a function of the speed trim system, not the stabilizer trim system. The FROM BASE AIRCRAFT: B-737-800 TO RELATED AIRCRAFT: B-737-8 differences table in the FSBR (shown in Figure 4) should be amended to accurately reflect MCAS as a function of the speed trim system.

FROM BASE AIRCRAFT: B-737-800 TO RELATED AIRCRAFT: B-737-8	DESIGN	REMARKS	FLT CHAR	PROC CHNG	TRAINING	CHECKING
	ATA 27 Flight Controls	STABILIZER TRIM: Maneuvering Characteristics Augmentation System (MCAS)	No	No	B	B

Figure 4. Table from FSBR to be revised

> **Action Item 11**: AEG should change STABILIZER TRIM to SPEED TRIM in the ATA 27 Flight Control row, remarks column contained in the FSBR differences table, FROM BASE AIRCRAFT B-737-800 TO RELATED AIRCRAFT B-737-8.

Resolution: Action item closed. FAA incorporated the intent of the change as documented in the FSB report appendix 3 Differences Tables/Design ATA 22 Autoflight. The TAB has evaluated the changes to the FSB report and found them acceptable.

2.5 Conclusion

The TAB found that the MCAS design changes are compliant and safe. The TAB's findings were based on the satisfactory resolution of eleven return to service action items. Additionally, the TAB identified eight future action items that should be addressed in a timely manner. Four out of the eight future action items were closed prior to B737MAX return-to-service.

Appendix A: Documentation

The following is a list of documentation that was provided to the TAB for evaluation:

- Boeing Report, 737-8/-9 Flight Crew Operations 25.1302 Compliance Report – FCC P12.1.2, dated May 22, 2020
- Boeing Report, 737-8/-9 Flight Crew Operations 25.1523 Compliance Report – FCC P12.1.2 Updates, dated May 22, 2020
- Development Assurance Accomplishment Summary
- Boeing Report 737 MAX Integrated Speed Trim System Safety Analysis, dated August 25, 2020
- Flight Test Certification Report, Stall Testing with EFS and/or STS Off, dated June 5, 2020
- Flight Test Pilot Report, Stall Testing with EFS and/or STS Off, dated September 10, 2019
- Flight Test Plan, Revision A, Control System Malfunction Testing with EFS and/or STS Failures, dated November 19, 2019
- Flight Test Plan, Stall Testing with EFS and/or STS Off, dated December 11, 2019
- Boeing Report, 737-7/8/8200/9/10 Certification Maintenance Requirements, dated July 2020
- Flight Test Plan 737 MAX Speed Trim System Inoperative Characteristics, dated June 24, 2020
- Flight Test Certification Report, 737 MAX Speed Trim System Inoperative Characteristics, dated July 14, 2020
- Boeing Report, Speed Trim System Compliance to 14 CFR 25.672(c)(2), dated July 16, 2020.
- Flight Test Pilot Report, 737 MAX Speed Trim System Inoperative Characteristics, dated June 4, 2020
- Flight Test Plan, 737 MAX Trim Re-Sync Failure SIM Certification Test, dated August 12, 2020
- Flight Test Certification Report, 737 MAX Trim Re-Synchronization Failure Simulator Certification Test, dated September 10, 2020
- Boeing Report, 737-7/-8/-9/-8200 Electrical Wire Interconnection System (EWIS) – System Safety Assessment, dated June 3, 2020
- Boeing Report, 737 NG/MAX Enhanced Digital Flight Control System, Autothrottle, and Yaw Damper Safety Analysis, dated August 26, 2020
- Boeing Report, Flight Crew Operation – Compliance Report – Crew Alerting, dated July 13, 2020
- Rockwell Collins Report, Plan for Software Aspects of Certification (PSAC) for the FCC-730 on the Boeing 737-NG/MAX, Dated May 13, 2020
- Boeing Report, 737 NG/MAX Enhanced Digital Flight Control System (EDFCS), Autothrottle, And Yaw Damper Safety Analysis, dated June 13, 2020
- Flight Test Plan, 737 MAX Enhanced Digital Flight Control System (EDFCS) P12.1.2 (R17.9.5) Flight Control Computer (FCC) Software Certification Simulator Test, dated May 19, 2020

- Flight Test Plan, 737 MAX Enhanced Digital Flight Control System (EDFCS) P12.1.2 Flight Control Computer (FCC) Software Certification Flight Test
- Flight Test Certification Report, 737 MAX Enhanced Digital Flight Control System (EDFCS) P12.1.2 Flight Control Computer (FCC) Software Certification Test, dated July 10, 2020
- Flight Test Pilot Report, 737 MAX Enhanced Digital Flight Control System (EDFCS) P12.1.2 Flight Control Computer (FCC) Software Engineering Flight Test
- Boeing Report, 737-8/-9 Stabilizer Trim Wheel Forces, dated June 19, 2020
- Boeing Report, Showing Compliance for Stall Identification Systems on the 737 MAX, dated June 19, 2020
- Boeing Report, Single and Multiple Failure Return to Service Accomplishment Summary 737 MAX Program, dated April 7, 2020
- Enclosure A, Operating Procedures to address certification of Enhanced
- Digital Flight Control System (EDFCS) software version P12.1.2, dated PENDING
- Flight Crew Operations Manual Bulletin, Revision v76, Speed Trim System (STS) and Autopilot Flight Director System (AFDS) with new Flight Control Computer (FCC) P12.1.2 software, dated pending.
- Flight Crew Operations Manual
- Boeing Message of the proposed revision to the 737-8/-9 to update various Operating Procedures to address certification of Flight Control Software Replacement version P12.1.2., dated October 2, 2020
- Boeing 737 MAX Flight Crew Training Manual, Revision v48c, dated January 30, 2019.
- Boeing Airpline Flight Manual RA-19-03050, Amendment 3, Operating Procedures to address certification of Flight Control Software Replacement version P12.1.2
- Rockwell Collins Software Accomplishment Summary, FCC-730 Operational Program Software on the Boeing 737-NG/MAX Version P12.1.2
- Rockwell Collins Software Configuration Index, FCC-730 Operational Program Software on the Boeing 737 MAX Version p12.1.2
- Boeing Report, 737 MAX Enhanced Digital Flight Control System (EDFCS) Development Assurance Accomplishment Summary – Software P12.1.2, dated October 15, 2020
- Boeing Alert Service Bulletin 737-22A1342, Original Issue, AUTO FLIGHT - Digital Flight Control System - Flight Control Computer Software Version P12.1.2 Change, dated October 16, 2020
- Boeing Report, 737NG/737MAX Enhanced Digital Flight Control System Certification Summary, dated October 15, 2020

Appendix B: Acronyms

AC	Advisory Circular
ACO	Aircraft Certification Office
AEG	Aircraft Evaluation Group
AFDS	Autopilot Flight Director System
AFHA	Airplane Functional Hazard Assessment
AOA	Angle of Attack
ARP	Aerospace Recommended Practice
ATC	Amended Type Certificate
ATP	Airline Transport Pilot
BASOO	Boeing Aviation Safety Oversight Office
BCA	Boeing Commercial Airplanes
CAA	Civil Aviation Authority
CARB	Corrective Action Review Board
CBT	Computer-Based Training
CMT	Certification Management Team
CPU	Central Processing Unit
CSRT	Critical Systems Review Team
CSTA	Chief Scientific And Technical Advisor
DOD	Department of Defense
EASA	European Union Aviation Safety Agency
eCAB	Boeing Engineering Simulator
EDFCS	Enhanced Digital Flight Control System
EDFCS	Enhanced Digital Flight Control System
EWIS	Electrical Wire Interconnection System
FAA	Federal Aviation Administration
FCC	Flight Control Computer
FFS	Full Flight Simulator
FOEB	Flight Operations Evaluation Board
FSB	Flight Standard Board
FSBR	Flight Standard Board Report
HDD	Head Down Display

IAS	Indicated Air Speed
ICAO	International Civil Aviation Organization
IP	Issue Paper
iSSA	Integrated Aircraft-Level System Safety Assessment
JOEB	Joint Operations Evaluation Board
LOFT	Line Oriented Flight Training
MCAS	Maneuvering Characteristics Augmentation System
MVS	Mid-Value Select
NSP	National Simulator Program
ODA	Organization Designation Authorizations
OJT	On-the-Job Training
PFD	Primary Flight Display
PMP	Project Management Professional
POI	Principal Operations Inspector
PSAC	Plan for Software Aspects Of Certification
QRH	Quick Reference Handbook
SACO	Seattle Aircraft Certification Office
SAE	Society of Automotive Engineers
SAS	Software Accomplishment Summary
SFHA	System Functional Hazard Assessments
S&MF	Single and Multiple Failure
SSA	System Safety Assessment
SOI	Stage of Involvement
STC	Supplemental Type Certificate
STS	Speed Trim System
TAB	Technical Advisory Board
TC	Type Certificate
TCCA	Transport Canada Civil Aviation
UAV	Unmanned Aerial Vehicle
UPRT	Upset Prevention and Recovery Training
USDOT	United States Department of Transportation