May 24, 2023
GAMA Publication #21

General Aviation Manufacturers Association

Boeing 737 MAX Related Reports & Recommendations and their Impact on Human Factors

A Report from the GAMA Flight Deck Human Factors Working Group

Submitted to

Federal Aviation Administration of the United States

European Union Aviation Safety Agency

Transport Canada Civil Aviation Directorate

Agência Nacional de Aviação Civil of Brazil

Contents

Abstract

As a result of the two catastrophic Boeing 737 MAX accidents, multiple safety recommendations were published from several organizations including the National Transportation Safety Board (NTSB), the Federal Aviation Administration (FAA), and the US House Committee on Transportation and Infrastructure. These safety recommendations include many Human Factors (HF) related aspects. The General Aviation Manufacturers Association (GAMA) charged its Flight Deck Human Factors Working Group (FDHFWG) to further review these recommendations, categorize them, and create recommendations for HF related to flight deck design and certification process.

The report identifies twelve major topics for the GAMA FDHFWG recommendations: Flightcrew Assumptions, Pilot Response Time, Representative Pilots, Human Factors Training, Aircraft and System Functional Hazard Assessments, Human Error Analysis, Means of Compliance, Changed Product Rule, AC/AMC 25.1302, Harmonization, and AFM/AOM/FCOM/FCTM. A total of 15 GAMA FDHFWG recommendations are provided for consideration to the industry and to regulators. Those include the creation of new design practices and potential updates to regulatory guidance material. Many of the original recommendations from the available official publications were found to be adequately addressed already today with respect to available methodologies or existence of supporting guidance material. In those cases, no further recommendations were made by GAMA FDHFWG. The report provides the context for each recommendation, links them to the original publications and provides a list of applicable regulations and industry standards related to the recommendation groupings.

The intended outcome of this report is to open a discussion with the certification authorities regarding the HF recommendations developed by the GAMA FDHFWG and to work collectively to seek improvement opportunities. This is a step to enable implementation of the recommendations from the original safety reports. This report provides an overview of the tasks completed by the GAMA FDHFWG including the methodology used to analyze the recommendations from these various publications.

1 Introduction

On 29th October 2018, Lion Air flight 610, crashed in the Java Sea shortly after takeoff from Soekarno-Hatta International Airport, Jakarta, Indonesia[1]. On 10th March 2019, Ethiopian Airlines flight 302, crashed near Ejere, Ethiopia, shortly after takeoff from Addis Ababa Bole International Airport, Ethiopia[2]. All passengers and crew on board were fatally injured, a total of 346 lives were lost. Both accidents involved the loss of a Boeing 737 MAX 8 aircraft. The FAA and other US bodies commissioned several studies to evaluate the initial certification of the 737 MAX, as well as the certification process itself. Multiple publications surfaced that are referenced in Section 2. Many of these official publications included HF related recommendations.

1.1 Task Objectives

The GAMA FDHFWG was tasked to develop practical HF recommendations for discussion with the Federal Aviation Administration (FAA), European Union Aviation Safety Agency (EASA), Transport Canada Civil Aviation Directorate (TCCA) and Agência Nacional de Aviação Civil (ANAC) and industry on if (and how) the issues and recommendations for HF related to design and certification process identified in 737 MAX reports [1-12] could be incorporated into regulatory guidance material and / or other methodologies. A key objective is for industry to collectively review the body of work published and work together with the certification Authorities to seek improvement opportunities.

This task is not focused on the root causes of accidents nor specific design aspects of the 737 MAX aircraft. Although, this tasking is focused on 14 Code of Federal Regulations (CFR) Part 25 aircraft, consideration should be given to the practical and appropriate application across Part 23, 27, and 29 aircraft.

1.2 Task Description

The task was initiated on 22nd February 2021.

At a high-level the GAMA FDHFWG conducted the following tasks:

1. Conducted a review of the various reports and publications related to the 737 MAX accidents and certification processes (reports are listed in Section 2) and identified

[1] Aircraft Accident Investigation Report, Lion Mentari Airlines, Boeing 737-8 (MAX); PK-LQP, FINAL KNKT.18.10.35.04, PT, Komite Nasional Keselamatan Transportasi (KNKT), Republic of Indonesia, October 2019.
[2] Interim Investigation Report on Accident to the B737-8 (MAX) Registered ET-AVJ operated by Ethiopian Airlines, Report No. AI-01/19, Ministry of Transport Aircraft Accident Investigation Bureau, The Federal Democratic Republic of Ethiopia, March 2020.

recommendations relating to human performance and error assessment as they relate to HF within the design and certification process;

2. Collated the recommendations from item #1 into common themes or topic areas. Aspects considered during the review process included HF task interactions related to the 14 CFR Part 25 aircraft design and certification process, with specific emphasis on key HF tasks performed during the following processes: requirements development and validation, evaluations, certification, competencies for HF experts, and the role of pilots and automation, etc.;
3. From the topic areas identified in item #2, using existing guidance material as a baseline, developed a practical set of GAMA recommendations to implement the recommendations identified in item #1 into certification authority guidance material and industry practices.

The intended outcome of this report is to open a discussion with the certification authorities regarding the HF recommendations developed by the GAMA FDHFWG and to work collectively to seek improvement opportunities.

2 737 MAX Reports Analyzed

[1] H.R. 8408 — 116th Congress: *Aircraft Certification Reform and Accountability Act*, November 2020.

[2] Senate Commerce Committee Investigation Report - *Aviation Safety Oversight* – prepared by Commerce Committee Majority [Republican] Staff, December 2020.

[3] Response to Official Report of the Special Committee on the Federal Aviation Administration's Aircraft Certification Process, Final Report, FAA, April 2020.

[4] GAMA/AIA Certification Stakeholder Review Meeting Minutes, Rev. 3 29th February 2020.

[5] The Boeing 737 MAX Aircraft: Costs, Consequences, and Lessons from its Design, Development, and Certification - Preliminary Investigative Findings, prepared by the Democratic Staff of the House Committee on Transportation and Infrastructure, March 2020.

[6] Official Report of the Special Committee to Review the Federal Aviation Administration's Aircraft Certification Process, January 2020.

[7] Boeing 737 MAX Flight Control System Joint Authorities Technical Review (JATR) – *FAA Certification Observations, Findings, and Recommendations*, October 2019.

[8] Aircraft Accident Investigation Report, Lion Mentari Airlines, Boeing 737-8 (MAX); PK-LQP, FINAL KNKT.18.10.35.04, PT, Komite Nasional Keselamatan Transportasi (KNKT), Republic of Indonesia, October 2019.

[9] Safety Recommendation Report, Assumptions Used in the Safety Assessment Process and the Effects of Multiple Alerts and Indications on Pilot Performance, Safety Recommendation Report ASR-19-01, National Transportation Safety Board, Washington DC, September 2019.

[10] US Office of the Special Counsel (OSC) File DI-19-2964, 2019 (https://osc.gov/Documents/Public%20Files/FY19/DI-19-2964/DI-19-2964%20Agency%20Report_Redacted.pdf)

[11] The Design, Development & Certification of the Boeing 737 MAX, Final Committee Report, The House Committee on Transportation and Infrastructure, September 2020.

[12] 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 2020.

3 Methodology

The effort of the GAMA FDHFWG was broken into four major tasks as shown in Figure 1. The task team comprised a subset of the larger FDHFWG and included HF experts from both Original Equipment Manufacturers (OEM) and avionics suppliers who work in Part 23, 25, 27, and 29 categories across the globe. The breadth of experience and knowledge within the working group allowed for unique viewpoints and extensive reviews of the content provided in this report. Each recommendation from the original safety reports [1-12] was thoroughly vetted through an iterative review process with multiple reviewers.

Figure 1. Methodology Overview

In Task 1, two individuals were assigned to each 737 MAX report listed in Section 2. The individuals read and extracted recommendations that were related to human factors. Those that were directly and tangentially related to HF were captured, to not inadvertently miss a possible recommendation (see Task 3 to remove recommendations not within the FDHFWG scope). The recommendations were merged into a single database and provided a recommendation identification (ID). The first portion of the recommendation ID includes the source reference number. The second portion of the recommendation ID, after the hyphen is the recommendation number within the reference. In practice there was no handover to Task 2, as the same team was involved in both tasks.

In Task 2, themes / topics areas were identified. Each recommendation was assigned to one or more themes / topic areas to help organize the recommendations. After initial assignment of the recommendations, it was observed that certain themes / topics areas were too detailed or did not adequately address the recommendation, and therefore the themes / topic areas were iterated several times during group review. At the conclusion of Task 2, there was a handover briefing to the Task 3 members to describe what had been completed and recommendations for Task 3. Note that many of the Task 1 and 2 members were also part of Task 3.

In Task 3, recommendations categories were each assigned to two team members for further review. The team assessed the existing set of recommendations to determine if they were related to HF. If they were out-of-scope they were marked as such and are not included within this report. Once the list of recommendations had been reduced to only in-scope recommendations, the recommendations were reviewed for similarities and a cross-reference was made for recommendations that were directly related to another recommendation. In Task 3, team members also identified applicable reference material e.g., FAA Advisory Circulars (AC) EASA Acceptable Means of Compliance (AMC), the proposed output, and the impacted stakeholders (e.g., industry or certification Authorities) for each recommendation. It should be noted that there are no HF recommendations from Ref.3 that were included in the analysis as this was the FAA response to Ref. 6. However, Ref. 6 recommendations were included in the analysis. Ref. 5 does not contain HF related recommendations and hence is not reflected in the final analysis. Ref. 10 recommendations were out of scope for the current analysis.

In Task 4, the team members reviewed the language of the original recommendation, ensured the appropriate output type was identified and that all applicable reference material was identified. The wording from reference material was captured and reviewed against the original recommendation to confirm the recommendation had not already been addressed. This processes effectively resulted in iterating a substantial portion of the Task 3 output.

The recommendation grouping was then modified based on the remaining recommendations and their common themes. Two team members were assigned to each recommendation grouping. The team members subsequently authored the final GAMA FDHFWG recommendations and recommendation context for their assigned groupings. The result of this process is that the GAMA FDHFWG recommendations are informed by the original set of recommendations within the 737 MAX reports. The original recommendations were modified in cases where they were already met by existing guidance or where the GAMA FDHFWG felt the recommended activity would be better suited for industry rather than certification Authorities (i.e., where an industry methodology may be better suited than the creation of certification guidance material). The final report was then prepared and reviewed, provided to the entire FDHFWG for a final review and released.

This report is divided by recommendation topics. For each GAMA FDHFWG recommendation, recommendation context is provided to justify the recommendation and provide clarity for future actions. For each recommendation topic, the applicable regulations and guidance are listed as well as the list of original recommendation numbers for reference. The original recommendation numbers correspond to the table in Appendix D that provides the wording of the original recommendation as well as the recommendation source.

4 Recommendations

4.1 Flightcrew Assumptions

GAMA Recommendation #1
Industry should create a methodology for the validation, documentation, and traceability of assumptions for flightcrew behavior and response (e.g., actions), including the effect(s) of failure conditions.

Recommendation Context

Flightcrew behavior assumptions are made in system level and aircraft level FHAs as required per 14 CFR 25.1309 and CS 25.1309. Guidance materials AC 25.1309 Draft ARSENAL and AMC 25.1309 describe the need to identify Failure Conditions (FCs), Effect on Aircraft, Flightcrew, and Effect on Occupants as well as the severity of those FCs. However, there is currently no guidance material on how to conduct an HF validation of FHAs assumptions, for instance, based on a structured methodology.

An industry methodology should be created on how to document, track and validate assumptions on flightcrew behavior, including the effects of failure conditions on the flightcrew. Considerations should be made for the assumed and required pilot training and knowledge, and the operational context in which failures may occur. Assumptions for flightcrew behavior should also include workload, response time, recognition, procedures, actions, errors, etc. The methodology should include proposed methods and real-world examples. See Section 4.5 of this report related recommendations on HF considerations in FHAs.

The methodology should cover the need for a representative set of pilots to be used in the validation of flightcrew behavior assumptions during development and test activities (see GAMA Recommendation #3 related to representative pilots).

Validation of crew response assumptions and workload should be done in isolation and in combination with other flight deck systems, as prescribed in AC/AMC 25.1302, as there may be unforeseen impacts resulting from interactions between these systems. It should not be limited to areas affected by design changes alone since there may be other unforeseen impacts resulting from interactions with unchanged areas. Validation of assumptions for flightcrew behavior should also include integrated flight deck effects that may be triggered or impacted by the failure conditions, and crew execution of the associated procedures.

The extent of the validation should be commensurate with the criticality of the flightcrew task, the level of confidence in the crew response assumptions, and the degrees of novelty, complexity, and integration, as discussed in AC/AMC 25.1302.

Note SAE S-18H, in coordination with SAE G-10, are in the process of developing a report(s) regarding human considerations in the Safety Assessment Process, which could be used to inform revisions of ARP4761 and ARP4754. In addition, EASA published Certification Memo SA-002 Issue 1 “Human Factors Considerations in Aircraft and System Functional Hazard Assessments" in 2022. In December 2022, the FAA published draft AC 25.1309-1B (System Design and Analysis) for public comment with the intention to harmonize with EASA AMC 25.1309. In November 2022, the EASA published NPA 2022-07 for public comment with the intention to update CS 25.1302 and AMC 25.1302.

GAMA Recommendation #1 is partially aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Sec. 119. Paragraph (c):

> *(c) EXPERT SAFETY REVIEW.—*
> *(1) IN GENERAL.—Not later than 30 days after the date of enactment of this title, the Administrator shall initiate an expert safety review of assumptions relied upon by the Administration and manufacturers of transport category aircraft in the design and certification of such aircraft.*
> *(2) CONTENTS.—The expert safety review required under paragraph (1) shall include—*
> *(A) a review of Administration regulations, guidance, and directives related to pilot response assumptions relied upon by the FAA and manufacturers of transport category aircraft in the design and certification of such aircraft, and human factors and human system integration, particularly those related to pilot and aircraft interfaces;*
> *(B) a focused review of the assumptions relied on regarding the time for pilot responses to non-normal conditions in designing such aircraft’s systems and instrumentation, including responses to safety-significant failure conditions and failure scenarios that trigger multiple, and possibly conflicting, warnings and alerts;*
> *(C) a review of human factors assumptions with applicable operational data, human factors research and the input of human factors experts and FAA operational data, and as appropriate, recommendations for modifications to existing assumptions;*
> *(D) a review of revisions made to the airman certification standards for certificates over the last 4 years, including any possible effects on pilot competency in basic manual flying skills;*
> *(E) consideration of the global nature of the aviation marketplace, varying levels of pilot competency, and differences in pilot training programs worldwide;*
> *(F) a process for aviation stakeholders, including pilots, airlines, inspectors, engineers, test pilots, human factors H. R. 133—1159 experts, and other aviation safety experts, to provide and discuss any observations, feedback, and best practices;*
> *(G) a review of processes currently in place to ensure that when carrying out the certification of a new aircraft type, or an amended type, the cumulative effects that new technologies, and the interaction between new technologies and unchanged systems for an amended type certificate,*

may have on pilot interactions with aircraft systems are properly assessed through system safety assessments or otherwise; and
(H) a review of processes currently in place to account for any necessary adjustments to system safety assessments, pilot procedures and training requirements, or design requirements when there are changes to the assumptions relied upon by the Administration and manufacturers of transport category aircraft in the design and certification of such aircraft.
(3) REPORT AND RECOMMENDATIONS.—Not later than 30 days after the conclusion of the expert safety review pursuant to paragraph (1), the Administrator shall submit to the congressional committees of jurisdiction a report on the results of the review, including any recommendations for actions or best practices to ensure the FAA and the manufacturers of transport category aircraft have accounted for pilot response assumptions to be relied upon in the design and certification of transport category aircraft and tools or methods identified to better integrate human factors throughout the process for such certification.
(4) INTERNATIONAL ENGAGEMENT.—The Administrator shall notify other international regulators that certify transport category aircraft type designs of the expert panel report and
encourage them to review the report and evaluate their regulations and processes in light of the recommendations included in the report.
(5) TERMINATION.—The expert safety review shall end upon submission of the report required pursuant to paragraph (3).
(6) REGULATIONS.—The Administrator shall issue or update such regulations as are necessary to implement the recommendations of the expert safety review that the Administrator determines are necessary to improve aviation safety.

Existing Guidance and Industry Standards Related to Crew Assumptions

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
FAA	AC 25.1302-1	5-6.b(1)(b) System Function Allocation 1-2.c Applicability
EASA	AMC 25.1302 Amdt. 27	5.7.5 Integration Related Workload and Error Figure 1 Methodical approach to planning certification for design related Human performance issues
FAA	AC 25.1309-1A	8.g(1) Failure warning
EASA	AMC 25.1309 Amdt. 26	9 Compliance with §/JAR 25.1309. 9.b.(5)(i).3 Crew and Maintenance Actions 11.b. Single failure conditions 11.d Depth of analysis 11.j Justification of assumptions, data sources, and analytical techniques
FAA	AC 25.1329-1C	Section 100.b(3) Pilot recognition Section 100.b(4) Pilot reaction time Section 103 Assessment of Human Factors
FAA	AC 25.1523-1	Section 5.c.4.viii Emergency and Non-Normal Situations
EASA	AMC 29.1302 Amdt. 9	3.2.5(a) Applicable HF design requirements 3.3.2(j)(1)(A) Objective data on crew member performance 3.3.2(j)(1)(I) Every design-related human performance issue 4.5 Crew member error management
FAA	Order 8110.4C	2-6(g) Analysis
SAE	ARP 4754A	All
EASA	Proposed CM No: CM-SA-002	Issue 01. Human Factors Considerations in Aircraft and System Functional Hazard Assessments. Point 4 – Flight Crew Response

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4.2 Pilot Response Time

GAMA Recommendation #2
Industry should develop a methodology for the demonstration of realistic pilot response time for failure conditions. The pilot response time should account for both pilot recognition and reaction.

Recommendation Context

14 CFR 25.255 (Out-of-trim characteristics) calls out the prescriptive use of three seconds for the evaluation of mis-trim conditions, especially for automatic trim systems where pilot recognition is relied upon to detect and arrest runaway failures. Per JATR Observation O2.8-C, although AC 25-7D, Flight Test Guide for Certification of Transport Category Airplanes, and AC 25.1329-1C, Approval of Flight Guidance Systems, provide guidance aimed at test pilots conducting test flights (with a recognition time of one second and a reaction time of one to three seconds), applicants seem to use this guidance as a design assumption that the pilot will be able to respond correctly within four seconds of the occurrence of a malfunction. Per JATR Finding F2.8-C, “There is a substantial difference between the situation of a test pilot who is testing a particular malfunction with precise foreknowledge of the malfunction to be tested and the proper response to be initiated, and the situation of a line pilot on a routine revenue flight who is not expecting any malfunction. Thus, guidance that is relevant to test flights may not be appropriate for routine revenue flights.”

The JATR report did not identify any studies that substantiate the FAA guidance concerning pilot recognition time and pilot reaction time (JATR Observation O2.8-D). In fact, several FAA studies with general aviation pilots demonstrate that these general aviation pilots may take many seconds, and in some cases many minutes, to recognize and respond to malfunctions (e.g., DOT/FAA/AM-97/24; DOT/FAA/AM-02/19; DOT/FAA/AM-05/23) (JATR Observation O2.8-E). A NASA study[3] of abnormal flight events with qualified, current, and active airline pilots also

[3] Casner, S.M., R.W. Geven, and K.T. Williams (2013). The Effectiveness of Airline Pilot Training for Abnormal Events, Human Factors, 55, 477-485.

found substantially longer recognition times and reactions times, even in the case of expected events, than the times given in AC 25-7D and AC 25.1329-1C (JATR Observation O2.8-F). Additionally, JATR Observation O2.8-G cites an analysis of aviation accidents that demonstrates that pilots may take a significantly longer time to recognize a malfunction and respond to it than the test flight guidance suggests. For example, the NTSB states: “When a flightcrew is confronted with a sudden, abnormal event, responses are more likely to be delayed or inappropriate.” (NTSB/AAR-14/01)

If the flightcrew does not respond within the prescribed time, assumptions made within the FHA may be invalid. The applicant needs to demonstrate that the required pilot response (including recognition) can be reasonably expected to be accomplished within the prescribed time.

Recommendation R3.8 from the JATR report recommended that the FAA should review the prescriptive use of three seconds under 14 CFR 25.255 (Out-of-trim characteristics) for the evaluation of mis-trim conditions, especially for automatic trim systems where pilot recognition is relied upon to detect and arrest runaway failures. This relates to the JATR recommendation R2.8 that suggests the FAA establish appropriate pilot recognition times and reaction times, based on substantive scientific studies which consider the operational environment, the circumstances under which malfunctions may occur, and the effect of surprise. In line with the JATR recommendations, the NTSB Safety Recommendation Report recommended the development of robust tools and methods for use in validating assumptions about pilot recognition and response to safety-significant failure conditions as part of the design certification process (Recommendation A-19-13).

GAMA FDHFWG recommends that systems be designed to account for realistic pilot response times based on particular system failure condition. Note, GAMA FDHFWG acknowledges that response time is not the sole factor, pilot recognition time and reaction time to a malfunction may depend on the particular nature of the malfunction, the circumstances under which it occurs, the corrective action required, and the individual pilot (JATR Finding F2.8-B). While standard prescriptive recognition and reaction time may be used, the assumed response time should be validated. The validation activities associated with pilot response times should consider the operational environment and circumstances of the non-normal conditions including the effect of surprise.

GAMA recommends the development of a methodology for the demonstration of adequate pilot response time using representative pilots within a representative operational environment. The demonstrated pilot response times should feed back into design changes, system safety assessment, human error analysis, etc. as appropriate. The newly created methodology could be referenced in an advisory circular once released.

FAA guidance for test flights in AC 25-7D, Flight Test Guide for Certification of Transport Category Airplanes, and AC 25.1329-1C, Approval of Flight Guidance Systems, require test

pilots to delay initiation of response to flight control or flight guidance malfunctions to account for pilot recognition time and pilot reaction time. AC 25.1329-1C (3)(b) recommends recognition time of at least one second and AC 25.1329-1C (4)(a) provides guidance for the recovery action initiation time after recognition per phase of flight (between one and three seconds). Per JATR Observation O2.8-B, "The current guidance recognizes that pilot recognition time may depend on various factors including the nature of the failure, but applicants are only required to prepare specific justification of their assumed recognition time if it is less than 1 second."

GAMA FDHFWG Recommendation #2 is partially aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Sec. 119. Paragraph (b)(c):

> *"(b) PILOT RESPONSE TIME.—Beginning on the day after the date on which regulations are issued under section 119(c)(6) of the Aircraft Certification, Safety, and Accountability Act, the H. R. 133—1158 Administrator may not issue a new or amended type certificate for an airplane described in subsection (a) unless the applicant for such certificate has demonstrated to the Administrator that the applicant has accounted for realistic assumptions regarding the time for pilot responses to non-normal conditions in designing the systems and instrumentation of such airplane. Such assumptions shall—*
> *"(1) be based on test data, analysis, or other technical validation methods; and*
> *"(2) account for generally accepted scientific consensus among experts in human factors regarding realistic pilot response time.*
> *"(c) DEFINITION.—In this section, the term 'transport airplane' means a transport category airplane designed for operation by an air carrier or foreign air carrier type-certificated with a passenger seating capacity of 30 or more or an all-cargo or combi derivative of such an airplane.".*
> *(b) CONFORMING AMENDMENT.—The analysis for chapter 447 of title 49, United States Code, is further amended by adding at the end the following:*
> *"44743. Pilot training requirements.".*
> *(c) EXPERT SAFETY REVIEW.—*
> *(1) IN GENERAL.—Not later than 30 days after the date of enactment of this title, the Administrator shall initiate an expert safety review of assumptions relied upon by the Administration and manufacturers of transport category aircraft in the design and certification of such aircraft.*
> *(2) CONTENTS.—The expert safety review required under paragraph (1) shall include—*
> *(A) a review of Administration regulations, guidance, and directives related to pilot response assumptions relied upon by the FAA and manufacturers of transport category aircraft in the design and certification of such aircraft, and human factors and human system integration, particularly those related to pilot and aircraft interfaces;*
> *(B) a focused review of the assumptions relied on regarding the time for pilot responses to non-normal conditions in designing such aircraft's systems and instrumentation, including responses to safety-significant failure conditions and failure scenarios that trigger multiple, and possibly conflicting, warnings and alerts;*

(C) a review of human factors assumptions with applicable operational data, human factors research and the input of human factors experts and FAA operational data, and as appropriate, recommendations for modifications to existing assumptions;
(D) a review of revisions made to the airman certification standards for certificates over the last 4 years, including any possible effects on pilot competency in basic manual flying skills;
(E) consideration of the global nature of the aviation marketplace, varying levels of pilot competency, and differences in pilot training programs worldwide;
(F) a process for aviation stakeholders, including pilots, airlines, inspectors, engineers, test pilots, human factors H. R. 133—1159 experts, and other aviation safety experts, to provide and discuss any observations, feedback, and best practices;
(G) a review of processes currently in place to ensure that when carrying out the certification of a new aircraft type, or an amended type, the cumulative effects that new technologies, and the interaction between new technologies and unchanged systems for an amended type certificate,
may have on pilot interactions with aircraft systems are properly assessed through system safety assessments or otherwise; and
(H) a review of processes currently in place to account for any necessary adjustments to system safety assessments, pilot procedures and training requirements, or design requirements when there are changes to the assumptions relied upon by the Administration and manufacturers of transport category aircraft in the design and certification of such aircraft.
(3) REPORT AND RECOMMENDATIONS.—Not later than 30 days after the conclusion of the expert safety review pursuant to paragraph (1), the Administrator shall submit to the congressional committees of jurisdiction a report on the results of the review, including any recommendations for actions or best practices to ensure the FAA and the manufacturers of transport category aircraft have accounted for pilot response assumptions to be relied upon in the design and certification of transport category aircraft and tools or methods identified to better integrate human factors throughout the process for such certification.
(4) INTERNATIONAL ENGAGEMENT.—The Administrator shall notify other international regulators that certify transport category aircraft type designs of the expert panel report and
encourage them to review the report and evaluate their regulations and processes in light of the recommendations included in the report.
(5) TERMINATION.—The expert safety review shall end upon submission of the report required pursuant to paragraph (3).
(6) REGULATIONS.—The Administrator shall issue or update such regulations as are necessary to implement the recommendations of the expert safety review that the Administrator determines are necessary to improve aviation safety.

Additionally, GAMA FDHFWG Recommendation #2 is partially aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Sec. 115. Paragraph (b):

> *(b) SYSTEM SAFETY ASSESSMENTS AND OTHER REQUIREMENTS.— In developing regulations under subsection (a), the Administrator shall—*
> *(1) require an applicant for an amended type certificate for a transport airplane to—*
> *(A) perform a system safety assessment with respect to each proposed design change that the Administrator determines is significant, with such assessment considering the airplane-level effects of individual errors, malfunctions, or failures and realistic pilot response times to such errors, malfunctions, or failures;*
> *(B) update such assessment to account for each subsequent proposed design change that the Administrator determines is significant;*
> *(C) provide appropriate employees of the Administration with the data and assumptions underlying each assessment and amended assessment; and*
> *(D) provide for document traceability and clarity of explanations for changes to aircraft type designs and system safety assessment certification documents; and*
> *(2) work with other civil aviation authorities representing states of design to ensure such regulations remain harmonized internationally.*

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
FAA	14 CFR 25.255	(a)(1) A three-second movement
EASA	CS 25.255 Amdt. 27	(a)(1) A three-second movement
EASA	AMC 25.255 Amdt. 27	1.1 The equivalent degree of trim
FAA	AC 25-7D	10.3.2.1.1 Section 25.255(a)(1)
FAA	AC 25.1309-1	8.g.(1) Failure warning or indication
EASA	AMC 25.1309 Amdt.27	Appendix 2(b) Identify and classify failure conditions
FAA	AC 25.1302-1	5-6.b.(1)(b) System Function Allocation
EASA	AMC 25.1302 Amdt. 27	5.5.2 System Function Allocation
EASA	AMC 29.1302 Amdt. 9	3.2.5(a) Applicable HFs design requirements 3.3.2(j)(1)(A) Methodological considerations applicable to HFs assessments 3.3.2(l)(1)-(8) Methodological considerations applicable to HFs assessments 4.5 Crew member error management
FAA	AC 25.1329-1C	100.b.(4) Pilot reaction time
EASA	AMC 25.1329 Amdt. 27	14.2.1.3 Pilot Reaction Time

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4.3 Representative Pilots

GAMA Recommendation #3
Industry should develop a methodology to define the role of the different types of pilots (e.g., flight test pilots, production test pilots, and certification authority pilots) and to identify what an appropriate representation of a qualified flightcrew should be for scenario-based human factors evaluations and tests.

Recommendation Context

The Report of the Special Committee to Review the FAA's Aircraft Certification Process recommended "Test and evaluation should include multiple failure mode scenarios and involve trained pilots who reflect the anticipated end-users of the product."

The current guidance in AC/AMC 25.1302 states that "the applicant may assume a qualified flightcrew is trained and checked in the use of the installed equipment". However, no other guidance exists on what is considered a qualified flightcrew. In November 2022, the EASA published NPA 2022-07 for public comment with the intention to update CS 25.1302 and AMC 25.1302.

Ideally, a set of pilots, representative of the end users, should be used within HF evaluations and tests throughout development and certification. The methodology should focus on how to determine a representative sampling including pilot characteristics (language, cultural diversity, anthropometric dimensions, etc.) and experience (e.g., flight experience or training).

Additionally, while not specifically mentioned in the original recommendations, the GAMA FDHFWG recommends that the methodology should include recommendations on the role of pilots within evaluations and tests, such as OEM pilots (flight test pilots, technical pilots, production test pilots), certification authority pilots, and other pilots such as "line pilots" (per AC 25.1523-1, Minimum Flightcrew).

GAMA FDHFWG Recommendation #3 is aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Section 128:

> *(a) PILOT OPERATIONAL EVALUATIONS.—Not later than 1 year after the date of enactment of this title, the Administrator shall revise existing policies for manufacturers of transport airplanes to ensure that pilot operational evaluations for airplane types that are submitted for certification utilize pilots from air carriers that are expected to operate such airplanes.*
> *(b) REQUIREMENT.—Such manufacturer shall ensure, to the satisfaction of the Administrator, that the air carrier and foreign air carrier pilots used for such evaluations include pilots of varying levels of experience.*

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
EASA	AMC 25.1302 Amdt. 27	Section 3. Scope and Assumptions 5.1 Applicability and Explanatory Material to CS 25.1302
FAA	AC 25.1302-1	3-3 Flightcrew Capabilities
EASA	AMC 25.1329 Amdt. 27	All
FAA	AC 25.1329-1C	100.b.(3) Pilot recognition 100.b.(4) Pilot reaction time 103 Assessment of human factors
FAA	AC 25.1523-1	5.c. Testing

Original Recommendations Informing the GAMA Recommendation

- 6-6
- 6-8

4.4 Human Factors Training

GAMA Recommendation #4
Industry should create a formal training course for Human Factors practitioners on how to incorporate Human Factors into the overall system development and aircraft certification process.

Recommendation Context

A formal training course for flight deck HF engineers that covers how to integrate Human Factors into the overall system development and aircraft certification process should be

developed. This course should focus on how to involve HF early in the process and how to integrate the methodology described in AC/AMC 25.1302 into the aircraft development and certification activities. The formal training course should be produced and administered with the support of the industry.

One example of a course, not necessarily endorsed by the GAMA FDHFWG, is the RTCA Human Factors Training course that focuses on DO-372 (https://www.rtca.org/training/human-factors/). The RTCA HF course provides a practical application of Human Factors Engineering (HFE) for a broad scope of personnel involved in the management, engineering, and operations of aircraft, however, it is not intended to cover the in-depth training required of flight deck Human Factors design and certification practitioners.

While this GAMA FDHFWG recommendation is not explicitly called out in any of the original recommendations, an underlying theme in the collective set of recommendations suggests that a course of this type would be extremely beneficial to the entire industry.

GAMA FDHFWG Recommendation #4 is partially aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Sec. 124. Paragraph (a):

> *(a) HUMAN FACTORS EDUCATION PROGRAM.—*
> *(1) IN GENERAL.—The Administrator shall develop a human factors education program that addresses the effects of modern flight deck systems, including automated systems, on human performance for transport airplanes and the approaches for better integration of human factors in aircraft design and certification.*
> *(2) TARGET AUDIENCE.—The human factors education program shall be integrated into the training protocols (as in existence as of the date of enactment of this title) for, and be routinely administered to, the following:*
> *(A) Appropriate employees within the Flight Standards Service.*
> *(B) Appropriate employees within the Aircraft Certification Service.*
> *(C) Other employees or authorized representatives determined to be necessary by the Administrator.*

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
RTCA	DO-372	All

Original Recommendations Informing the GAMA Recommendation

- 1-3

4.5 Aircraft and System Functional Hazard Assessments

GAMA Recommendation #5
Industry should create tools and methods for Human Factors considerations in Functional Hazard Assessments.

Recommendation Context

Various regulatory and industry material discuss failure conditions; however, no single source describes the HF aspects to consider as part of Aircraft Functional Hazard Assessments (AFHA) and System Functional Hazard Assessments (SFHA). Note that this recommendation does differ from Recommendation #1 as it focuses on failure conditions alone. Recommendation #1 has a broader coverage of flight crew assumptions, including non-failure conditions.

The JATR recommendations suggest that the FAA should develop tools and methods for HF evaluations; this is contrary to FAA Order 8110.4C 2-6(g): "*The FAA approves the data, not the analytical technique, so the FAA holds no list of acceptable analyses, approved computer codes, or standard formulas. Use of a well-established analysis technique is not enough to guarantee the validity of the result. The applicant must show the data are valid. Consequently, the ACO and its representatives are responsible for finding the data accurate, and applicable, and that the analysis does not violate the assumptions of the problem.*"

Rather, the GAMA FDHFWG proposes that the industry standard should identify tools and methods that can be used to support the process on how to integrate HF in FHA creation and validation. Additionally, the industry standard should include design and analysis methodologies and approaches capable of identifying failure interactions among systems. The emphasis should be on the applicant validating the data through tools and methods and the ACO reviewing the analysis for finding the data accurate and applicable. The newly created tools and methods could be referenced by an AC/AMC once released.

Whilst many of the JATR recommendations in this area are largely addressed by AC 25.1302-1, AMC 25.1302 Amdt. 27, RTCA DO-372, AC 25.1309-1A, AMC 25.1309 Amdt. 27, and EASA DRAFT CM-SA-002 Issue 1 (Human Factors Considerations in Aircraft and System Functional Hazard Assessments), it is recognized that a feedback (closed) loop needs to exist between HF and FHAs.

The proposed EASA CM-SA-002[4] is intended to provide information related to HF considerations in FHAs, however, the GAMA FDHFWG recommendation is for industry to

[4] EASA CM No.: Proposed CM-SA-002 Issue 01, Human factors Considerations in Aircraft System Functional Hazard Assessments

create tools and methods. Aspects to consider are, for example, assumptions regarding flightcrew characteristics, validating assumptions regarding flightcrew behavior, flightcrew error (see Section 4.6 for Human Error Analysis), method and criteria to determine the “Effect on Flight Crew” portion of the severity per AC/AMC 2X.1309, and use of evaluations and tests to validate the FHA.

FHAs are covered by AC 25.1309 Draft ARSENAL. EASA AMC 25.1309 Amdt. 27 provides further details. The proposed EASA CM-SA-002 Issue 1 provides some details on level of required HF scrutiny depending on confidence degree and provides a task analysis framework.

As described in the proposed EASA CM-SA-002 Issue 1, both CS 25.1302 and CS 25.1309 deal with human performance including human errors. The results of the assessments performed to address CS 25.1302 or equivalent, therefore should be used, where relevant and appropriate, to complement the human error portion of the safety assessment process.

The proposed EASA CM-SA-002 Issue 1 concludes that no existing guidance material neither AMC 25.1309 nor in AMC 25.1302 provides a dedicated and structured HF methodology for validating the assumptions made in the FHAs.

A more detailed process should be captured within tools and methods that go beyond just HF involvement in the validation of FHAs but describes the entire HF and FHA integration. This should include guidelines on how to take the lessons learned on flightcrew behavior from all HF activities throughout the development process and build them into an effective training syllabus for pilots.

As HF personnel prepare for evaluations/tests, it is recommended that they coordinate with the Safety team to understand the specific safety assumptions that are being made that involve pilot interaction. If a safety assumption involves pilot interaction, it should be assessed appropriately to determine the level of confidence of the assumption.

It is understood that the HF team cannot and should not attempt to evaluate every failure condition that could exist in each system. Therefore, this process will help narrow down and select specific conditions to evaluate. In return, the data that comes from the HF evaluation/test can help substantiate the assumption in the FHAs.

Through this feedback loop, the safety team can help determine the specific set of non-normals and failure conditions that should be evaluated by the HF team, and the HF team can provide the data from those evaluations back to the safety team.

Note SAE S-18H, in coordination with SAE G-10, are in the process of developing a report(s) regarding human considerations in the Safety Assessment Process, which could be used to inform revisions of ARP4761 and ARP4754. In December 2022, the FAA published draft AC

25.1309-1B (System Design and Analysis) for public comment with the intention to harmonize with EASA AMC 25.1309. In November 2022, the EASA published NPA 2022-07 for public comment with the intention to update CS 25.1302 and AMC 25.1302.

GAMA FDHFWG Recommendation #5 is partially aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Sec. 119. Paragraph (c):

> *(c) EXPERT SAFETY REVIEW.—*
> *(1) IN GENERAL.—Not later than 30 days after the date of enactment of this title, the Administrator shall initiate an expert safety review of assumptions relied upon by the Administration and manufacturers of transport category aircraft in the design and certification of such aircraft.*
> *(2) CONTENTS.—The expert safety review required under paragraph (1) shall include—*
> *(A) a review of Administration regulations, guidance, and directives related to pilot response assumptions relied upon by the FAA and manufacturers of transport category aircraft in the design and certification of such aircraft, and human factors and human system integration, particularly those related to pilot and aircraft interfaces;*
> *(B) a focused review of the assumptions relied on regarding the time for pilot responses to non-normal conditions in designing such aircraft's systems and instrumentation, including responses to safety-significant failure conditions and failure scenarios that trigger multiple, and possibly conflicting, warnings and alerts;*
> *(C) a review of human factors assumptions with applicable operational data, human factors research and the input of human factors experts and FAA operational data, and as appropriate, recommendations for modifications to existing assumptions;*
> *(D) a review of revisions made to the airman certification standards for certificates over the last 4 years, including any possible effects on pilot competency in basic manual flying skills;*
> *(E) consideration of the global nature of the aviation marketplace, varying levels of pilot competency, and differences in pilot training programs worldwide;*
> *(F) a process for aviation stakeholders, including pilots, airlines, inspectors, engineers, test pilots, human factors H. R. 133—1159 experts, and other aviation safety experts, to provide and discuss any observations, feedback, and best practices;*
> *(G) a review of processes currently in place to ensure that when carrying out the certification of a new aircraft type, or an amended type, the cumulative effects that new technologies, and the interaction between new technologies and unchanged systems for an amended type certificate,*
> *may have on pilot interactions with aircraft systems are properly assessed through system safety assessments or otherwise; and*
> *(H) a review of processes currently in place to account for any necessary adjustments to system safety assessments, pilot procedures and training requirements, or design requirements when there are changes to the assumptions relied upon by the*

Administration and manufacturers of transport category aircraft in the design and certification of such aircraft.
(3) REPORT AND RECOMMENDATIONS.—Not later than 30 days after the conclusion of the expert safety review pursuant to paragraph (1), the Administrator shall submit to the congressional committees of jurisdiction a report on the results of the review, including any recommendations for actions or best practices to ensure the FAA and the manufacturers of transport category aircraft have accounted for pilot response assumptions to be relied upon in the design and certification of transport category aircraft and tools or methods identified to better integrate human factors throughout the process for such certification.
(4) INTERNATIONAL ENGAGEMENT.—The Administrator shall notify other international regulators that certify transport category aircraft type designs of the expert panel report and
encourage them to review the report and evaluate their regulations and processes in light of the recommendations included in the report.
(5) TERMINATION.—The expert safety review shall end upon submission of the report required pursuant to paragraph (3).
(6) REGULATIONS.—The Administrator shall issue or update such regulations as are necessary to implement the recommendations of the expert safety review that the Administrator determines are necessary to improve aviation safety.

GAMA Recommendation #6
Industry should create a methodology on how to implement a closed feedback loop between relevant in-service data, Human Factors evaluations/tests, and the design and Functional Hazard Assessments.

Recommendation Context

Steps are required to ensure a total system approach to safety, linking all safety requirements from type certification to pilot training, and operational performance of the product.

A summary document explaining FHA assumptions (e.g., on pilot behavior) and conclusions relevant to safe operation should be communicated throughout the development process and to training providers and operators. Operators should be encouraged to monitor leading indicators to validate the assumptions of the FHA once the product enters service, and these processes may be an update to in-service monitoring as described in SAE ARP5150A. Updates to SAE ARP 4761 may be needed to incorporate the feedback from in-service monitoring.

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
SAE	ARP5150A	All
SAE	ARP4761	Appendix A. Functional Hazard Assessment.
EASA	AMC 29.1302 Amdt. 9	3.3. Certification strategy and methodologies 3.3.1. (a)(b)(c)(d) Certification strategy 3.3.2. (a)(b)(c)(d)(e)(f)(g)(h)(i)(j)(k)(l)(m)(n) Methodological considerations applicable to HFs assessments
FAA	AC 25.1309-1A	8.g. Acceptable means of compliance with 25.1309(c). 11.a. Flightcrew Action.
EASA	AMC 25.1309 Amdt. 27	8. Safety Objective. 9.b.(5) Crew and Maintenance Actions. 10. Identification of Failure Conditions and Considerations when Assessing their Effects. 12.a. Flight Crew Action.
EASA	CM-SA-002 Issue 1	3.1. Task Analysis Framework 3.2. Process Considerations 3.3. Traceability
FAA	Order 8110.4C	2-6(g) Implementation - Analysis

Original Recommendations Informing the GAMA Recommendation(s)

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4.6 Human Error Analysis (HEA)

GAMA Recommendation #7
Industry should create a methodology on how to perform a Flight Crew Human Error Analysis.

Recommendation Context

Applicants are already required per 14 CFR 25.1302 and CS 25.1302 to address potential flightcrew errors in the design of installed systems and equipment for use by the flightcrew. There are guidance materials AC 25.1302-1 and AMC 25.1302 describing the need to consider flightcrew error management in the certification planning, presenting design considerations and guidance and the acceptable means of compliance. However, there is currently no known industry guidance material on how to conduct an assessment on flightcrew error, for instance, based on a Human Error Analysis (HEA) method.

The GAMA FDHFWG recommends that the industry create a methodology for how to perform a HEA. Industry should be invited to propose methods and real-world examples of the application of those methods. The newly created methodology should be referenced by an AC/AMC once released.

Aspects to consider are, for example, method to identify tasks in which flightcrew error could occur in normal conditions and non-normal conditions (e.g., system failure conditions as defined in FHAs), assumptions regarding flightcrew characteristics, validating assumptions regarding flightcrew behavior, means to mitigate the effect of the flightcrew error, criteria to determine the severity of the flightcrew error, and use of evaluations and tests in conjunction with the HEA (for those flightcrew errors observed).

Information from the HEA should feed back into the design to ensure the system is sufficiently error tolerant (e.g., error detection and error recovery).

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
FAA	AC 25.1302-1	2-1 Human Error. 5-7 Flightcrew Error Management.
EASA	AMC 25.1302 Amdt. 27	5.6 Flight Crew Error Management.
EASA	AMC 25.1309 Amdt. 27	9.c. Compliance with CS 25.1309(c). 12. Operational and Maintenance Considerations.

Original Recommendations Informing the GAMA Recommendation(s)

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4.7 Acceptable Means of Compliance 25.671

GAMA Recommendation #8
EASA should consider expanding AMC 25.671 Control Systems and the FAA should harmonize with AMC 25.671 so that the applicant obtains early concurrence of the certification authority on the choice of an acceptable means of compliance.

Recommendation Context

Recommendation R3.1 from the JATR report states:

- The FAA should ensure early involvement by applicants and the FAA in the establishment of the detailed means of compliance for SSA demonstration (e.g., 14 CFR §§ 25.1309 (Equipment, Systems, and Installations) and 25.671 (Control Systems – General)), especially in case any deviations from standard guidance are planned, or if additional guidance not originally intended for §§ 25.1309 and 25.671 is expected to be part of the compliance demonstration.

Currently there is no specific FAA AC related to 25.671 (Control Systems - General) and EASA AMC 25.671 does not have language requiring the applicant to obtain early concurrence of the certification authority on the choice of an acceptable means of compliance.

> AMC 25.1309 Section 9 contains wording: "*This paragraph describes specific means of compliance for CS 25.1309. The applicant should obtain early concurrence of the certification authority on the choice of an acceptable means of compliance.*"

The GAMA FDHFWG recommends that similar language should be added to AMC 25.671 (and harmonized with FAA) to meet the intent of the recommendation. It should be noted that the FAA published draft AC 25.671 Control Systems—General in December 2022 for public comment. In December 2022, the FAA published draft AC 25.1309-1B (System Design and Analysis) for public comment with the intention to harmonize with EASA AMC 25.1309.

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
FAA	14 CFR 25.671	All
EASA	CS 25.671 Amdt. 27	All
EASA	AMC 25.671 Amdt. 27	All
EASA	AMC 25.1309 Amdt. 27	Section 9 – Compliance with CS 25.1309.

Original Recommendations Informing the GAMA Recommendation(s)

- 7-65

4.8 Changed Product Rule

GAMA Recommendation #9
The FAA should review the Changed Product Rule and consider expanding the guidance to cover the impact of changes to the roles and responsibilities of the flightcrew, procedures for the safe operation of the aircraft, and qualifications and training of the flightcrew, especially when making a determination of a "substantial change".

Recommendation Context

The JATR recommendations related to the application of the Changed Product Rule (14 CFR § 21.19 & §21.101) and associated guidance material (e.g., AC 21.101-1B and the FAA Orders 8110.4C and 8110.48A) should be revised (and harmonized) to require a top-down approach whereby every change is evaluated from an integrated whole aircraft system perspective. However, it should be noted that AC & AMC 25.1302-1 do cover installed equipment from an integrated ("individually and in combination") point of view. For example, AC 25.1302-1 states:

- Section 4-2a*: The applicant must show that these (installed systems and equipment for use by the flight crew) systems, and that proposed equipment, individually and in combination with other such systems and equipment, are designed so that qualified flight crew members can safely perform all of the tasks associated with the installed systems' and equipment's intended function;*
- Section 5-2c1(b): *The words "individually and in combination with other such equipment" from the introduction to § 25.1302 mean that showing compliance with the requirements of this rule for any particular equipment must consider its use in context with other installed equipment, including flight controls, and not simply in isolation*.

JATR Recommendation R9 suggests that the human factors team and representative flightcrews be involved during the certification process. Additionally, R9 states that the FAA should be provided all system differences between related aircraft to adequately evaluate operational impact, systems integration, and human performance.

Another key point made in the JATR recommendations was that the current regulatory guidance for the Changed Product Rule does not explicitly consider changes in the roles and responsibilities of the flightcrew, procedures for the safe operation of the aircraft, and qualifications and training of the flightcrew when deciding what is a “substantial change.” These aspects could be tied to AC 21.101-1B. In Section 3.2.3 of AC 21.101-1B, it may be helpful to clarify that the high-level descriptors should include a summary of the changes to the roles and responsibilities of the flightcrew, procedures for the safe operation of the aircraft, and qualifications and training of the flightcrew. In Section 3.6.1, when determining the design change as Substantial, Significant, or Non-Significant, the AC could provide details and examples regarding how the following aspects are used in this regard: changes to the roles and responsibilities of the flightcrew, procedures for the safe operation of the aircraft, and qualifications and training of the flightcrew. Additional material to describe changes to the roles and responsibilities of the flightcrew, procedures for the safe operation of the aircraft, and qualifications and training of the flightcrew could be added to Section 3.9.4.3.

GAMA FDHFWG Recommendation #9 is partially aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Sec. 117. CHANGED PRODUCT RULE Paragraphs (b)(3) (A), (E) and (F):

> *(3) CONTENTS.—In taking actions required under paragraph (2), the Administrator shall do the following:*
> *(A) Ensure that proposed changes to an aircraft are evaluated from an integrated whole aircraft system perspective that examines the integration of proposed changes with existing systems and associated impacts.*
> *(E) Develop objective criteria for helping to determine what constitutes a substantial change and a significant change.*
> *(F) Implement mandatory aircraft-level reviews throughout the certification process to validate the certification basis and assumptions.*

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
FAA	14 CFR §§ 21.101	All
FAA	14 CFR §§ 21.19	All
FAA	AC 21.101-1B	2.2.2.1 Section 21.101(b) 3.2.3 Use High Level Descriptors 3.6.1 Step 5. Is Each Related or Unrelated Group a Significant Change? 3.9.4 Consider the Following Aspects of a Type Design Change
FAA	Order 8110.4C	All
FAA	Orders 8110.48A	All
FAA	AC 25.1302-1	5-8.Integration 4-2.b - Scope of the Flightdeck Certification Program 5-1 Design Considerations and Guidance 5-2 Applicability of Material to § 25.1302

Original Recommendations Informing the GAMA Recommendation(s)

- 4-5
- 6-11
- 6-13
- 7-1
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4.9 Advisory Circular/Acceptable Means of Compliance 25.1302

GAMA Recommendation #10
The FAA should consider including additional guidance in AC 25.1302-1 for changes to a design in cases where the changed product process will be used and harmonize with EASA AMC 25.1302.

In addition, AC/AMC 25.1302 could be expanded to include how the assessment of novelty, complexity, and integration apply within the changed product rule.

Whilst the original (JATR) recommendations [Ref. 7] in this area are largely addressed by RTCA DO-372 (Section 2.3) and AC 25.1302-1 (§4-1, and in §5-2 and §5-3) relating to certification planning and early engagement of the certification authorities, there appears to be an opportunity to provide explicit additional guidance for cases where the changed product process is used. It would help foster the discussions and compliance focus areas at an early stage of the

certification program. Overall, this would improve the efficiency of the certification program and set expectations at an early stage of the process.

Two of the original recommendations (in the source documents) related to AC 25.1302-1 focused on the overall integration and emphasis of HF and human system integration throughout the certification process, and the expansion of FAA aircraft certification resources in Human Factors and human system integration to enable a thorough verification of compliance with 14 CFR § 25.1302. AC / AMC 25.1302-1 and RTCA DO-372 provide guidance related to certification planning to cover the recommended steps during the engineering design and certification process.

Observation O2.2-A from the JATR report [Ref. 7] indicates that the application of CFR 25.1302 to areas of change is not explicitly described in AC 25.1302-1. Further the source documents included a treatment of how/if AC 25.1302-1 is applied across all safety-critical functions and failure modes associated with a change under the changed product rule (and not just for novel, complex and/or integrated features). Guidance material such as AC 25.1302-1, 4-2.b(3), AMC 25.1302, 4.1, and AMC 25.1302, 4-1(c) do provide good context for the early assessment of complexity, integration and novelty. An explicit focus on changed areas and impact to level of scrutiny would be valuable addition for applicants and help foster early agreements with the certification agency on certification planning for key areas such as means of compliance.

AC 25.1302-1, Section 4-2, paragraph a, states that: "*The objective of this analysis is to improve understanding about how flight crew tasks are affected by the proposed system(s), components, and features.*"

AMC 25.1302, Section 4.1, paragraph 2, states that: "*The objective is to improve understanding about how flight crew tasks might be changed or modified as a result of introducing the proposed system(s), components and features.*"

Harmonization between the AC and AMC should be considered to meet the intent of the recommendation, i.e., clarify the acceptability (or not) of using 14 CFR 25.1302 in changed areas. In November 2022, the EASA published NPA 2022-07 for public comment with the intention to update CS 25.1302 and AMC 25.1302.

GAMA Recommendations #11
The FAA should consider expanding AC 25.1302-1 to provide further guidance on how both single and multiple failures are assessed, and any provisions necessary for adequate HMI following the failure(s).

Recommendation Context

The original published recommendations cover the relationship and applicability of AC 25.1302 to system failures (both single failures and any subsequent related failures). A key component of these original recommendations is that the applicant should ensure that failures of related systems are assessed taking into account human performance and the operational environment. AC/AMC 25.1302 do contain language covering failure conditions. For example, AC 25.1302-1 includes: sensor failure impacts in Section 5-7 e(2); system failure impacts on accessibility of controls in 5-4d(3); accessibility of information for continued safe flight and landing in 5-5c(1)(a); and system functional allocation in 5-6 b(b). However, further guidance on how single and multiple related failures should be assessed by the applicant would greatly assist the applicant and certification authority.

In November 2022, the EASA published NPA 2022-07 for public comment with the intention to update CS 25.1302 and AMC 25.1302.

GAMA Recommendation #12
Certification applicants should perform a review of system design changes that rely on original aircraft- and system- level assumptions that they are relying on to ensure they are not inconsistent with those assumptions.

In addition, industry should develop a methodology (e.g., a checklist with a decision tree) to determine the impact of discrete changes at the aircraft and system level to ensure that new changes are not inconsistent with the original design assumptions

Recommendation Context

The original JATR recommendation states:

- To the extent applicants rely on original aircraft- and system- level assumptions, the FAA should ensure the applicants perform a thorough review of system design changes to ensure they are not inconsistent with those assumptions.

Ref. 7 states, “The same assumptions for flightcrew responses to erroneous Angle of Attack (AOA) were carried over from previous programs without formal validation” and without the added impact of Maneuvering Characteristics Augmentation System (MCAS) functionality.

This implies that the impacted set of flight deck effects needs to be scrutinized with a changed system. The process needs to adequately address the cumulative effects of design changes and an analysis of the applicable interactions at the aircraft level. Whilst AC 25.1302-1 does cover the assessment of systems “individually and in combination with other such equipment” (e.g., Section 5-2, 5-8), this particular aspect is not explicitly called out.

In some cases, it may be necessary to deviate from previous design assumptions for a variety of reasons, so any analysis needs to account for that as well as call-out that any appropriate inconsistencies are identified and documented to the appropriate stakeholders. Any methodology should specify what to do when there is an inconsistency, such as impact analysis and mitigation action.

GAMA FDHFWG Recommendation #12 is partially aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Sec. 115. Paragraph (b)(1):

> *(b) SYSTEM SAFETY ASSESSMENTS AND OTHER REQUIREMENTS.— In developing regulations under subsection (a), the Administrator shall— H. R. 133—1153*
> *(1) require an applicant for an amended type certificate for a transport airplane to—*
> *(A) perform a system safety assessment with respect to each proposed design change that the Administrator determines is significant, with such assessment considering the airplane-level effects of individual errors, malfunctions, or failures and realistic pilot response times to such errors, malfunctions, or failures;*
> *(B) update such assessment to account for each subsequent proposed design change that the Administrator determines is significant;*
> *(C) provide appropriate employees of the Administration with the data and assumptions underlying each assessment and amended assessment; and*
> *(D) provide for document traceability and clarity of explanations for changes to aircraft type designs and system safety assessment certification documents.*

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
FAA	AC 21.101-1B	All
FAA	AC 25.1302-1	4.1 Certification Planning 4-2 Scope of the Flightdeck Certification Program 5-1, f(3) Design Considerations and Guidance 5-2 Applicability of Material to § 25.1302 5-3 Intended Function and Associated Flight Crew Tasks 5-7.a.(7)(a) Flightcrew Error Management 5-8 Integration
EASA	AMC 25.1302 Amdt. 27	3 Scope And Assumptions 4 Certification Planning 4.1 Scope of the Flight Deck Certification Programme 5.1 Applicability and Explanatory Material to CS 25.1302
RTCA	DO 372	2.3 Recommended Process

Original Recommendations Informing the GAMA Recommendation(s)

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4.10 Harmonization

GAMA Recommendation #13
The FAA and EASA should consider harmonizing guidance materials AC 25.1329-1C, AMC 25.1329, AC 25-7D and AMC 25.255.

Recommendation Context

14 CFR 25.255 (a)(1) prescribes the use of three seconds for the evaluation of out-of-trim conditions, especially for automatic trim systems where pilot recognition is relied upon to detect and arrest runaway failures. CS 25.255 (a)(1) has same requirement. This prescriptive time may not be appropriate for all trim speeds, especially where pilot recognition is relied upon for detection. For automatic trim systems, the three-second reaction time also may not be appropriate, depending on the cockpit alerting philosophy and trim system architecture and controls.

AMC 25.255 Section 1.1 acknowledges that: "particular characteristics of each aeroplane must be considered." while AC 25-7D Section 10.3.2.1.1 acknowledges different systems have different response rates to determine conditions based more on performance than specific timing. The GAMA FDHFWG recommends that AC 25-7D and AMC 25.255 should be harmonized.

Recommendation A-19-13, from NTSB report calls for the development of tools and methods for use in validating assumptions about pilot recognition and response to safety-significant failure conditions as part of the design certification process. Recommendation A-19-14, from NTSB report calls for, once the tools and methods have been developed as recommended in Recommendation A-19-13, revise existing FAA regulations and guidance to incorporate their use and documentation as part of the design certification process, including re-examining the validity of pilot recognition and response assumptions permitted in existing FAA guidance. The GAMA FDHFWG suggests that guidance material AC 25.1329-1C, AMC 25.1329 and AC 25-7D should be considered for revision once these tools and methods are developed.

The GAMA FDHFWG recommends that revised guidance material should be harmonized as per the acceptability as means of compliance of the developed tools and methods for use in validating assumptions about pilot recognition and response to safety-significant failure conditions as part of the design certification process.

GAMA FDHFWG Recommendation #13 is partially aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Sec. 115. Paragraph (b)(2):

> *(b) SYSTEM SAFETY ASSESSMENTS AND OTHER REQUIREMENTS.— In developing regulations under subsection (a), the Administrator shall— H. R. 133—1153*
> *(2) work with other civil aviation authorities representing states of design to ensure such regulations remain harmonized internationally.*

GAMA Recommendation #14
The FAA should consider harmonizing AC 25.1309-1 with EASA AMC 25.1309 Amdt. 27.

Recommendation Context

Based on the recommendations from the 737 MAX reports, GAMA FDHFWG believes FAA AC 25.1309-1 would benefit from being harmonized with EASA AMC 25.1309-1. It is understood that an FAA DRAFT Arsenal document for AC 25.1309 is available, but not easily accessible for future applicants.

In December 2022, the FAA published draft AC 25.1309-1B (System Design and Analysis) for public comment with the intention to harmonize with EASA AMC 25.1309.

AMC 25.1309, Section 9 contains wording: *"This paragraph describes specific means of compliance for CS 25.1309. The applicant should obtain early concurrence of the certification authority on the choice of an acceptable means of compliance."*

The GAMA FDHFWG recommends that similar wording should be added to AC 25.1309 to meet the intent of the recommendation, i.e., applicants should obtain early concurrence of the certification authority on the choice of an acceptable means of compliance.

Recommendation A-19-13, from the NTSB report asks for the development of tools and methods for use in validating assumptions about pilot recognition and response to safety-significant failure conditions as part of the design certification process.

Recommendation A-19-13, from the NTSB report asks for, once the tools and methods have been developed as recommended in Recommendation A-19-13, revise existing FAA regulations and guidance to incorporate their use and documentation as part of the design certification process, including re-examining the validity of pilot recognition and response assumptions permitted in existing FAA guidance.

The GAMA FDHFWG suggests that guidance material AC 25.1309-1A and AMC 25.1309 should be considered for revision once these tools and methods are developed.

The GAMA FDHFWG recommends that revised guidance material should be harmonized as per the acceptability as means of compliance of the developed tools and methods for use in validating assumptions about pilot recognition and response to safety-significant failure conditions as part of the design certification process.

AMC 25.1309 Paragraph 9 (c)(3) states that: *"In the case of aeroplane conditions requiring immediate crew action, a suitable warning indication must be provided to the crew, if not provided by inherent aeroplane characteristics. In either case, any warning should be rousing*

and should occur at a point in a potentially catastrophic sequence where the aeroplane's capability and the crew's ability still remain sufficient for effective crew action."

GAMA FDHFWG recommends that similar wording should be added to AC 25.1309 to meet the intent of the recommendation i.e., the alert should be rousing and should occur at a point in a potentially catastrophic sequence where the aeroplane's capability and the crew's ability remain sufficient for effective crew action.

14 CFR 25.1309 differs from CS 25.1309 in this paragraph (c) where the former lacks reference to “timely manner” when associated to the appropriate flightcrew corrective action.

EASA CS 25.1309 (c) states that: *“Information concerning unsafe system operating conditions must be provided to the flight crew to enable them to take appropriate corrective action in a timely manner…”*

FAA 14 CFR 25.1309 (c) states that: *“Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action…”*

The GAMA FDHFWG recommends that 14 CFR 25.1309 (c) should harmonize with CS 25.1309 (c) to include the notion of timeliness i.e.: "in a timely manner".

The GAMA FDHFWG Recommendation #14 is partially aligned with the Aircraft Certification, Safety and Accountability Act (ACSAA) Sec. 115. Paragraph (b)(2):

> *(b) SYSTEM SAFETY ASSESSMENTS AND OTHER REQUIREMENTS.— In developing regulations under subsection (a), the Administrator shall— H. R. 133—1153*
> *(2) work with other civil aviation authorities representing states of design to ensure such regulations remain harmonized internationally.*

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
FAA	14 CFR 25.255	Out-of-trim characteristics – requirement (a)(1) "A three-second movement of the longitudinal trim system…"
EASA	CS 25.255 Amdt. 27	Out-of-trim characteristics – requirement (a)(1) "A three-second movement of the longitudinal trim system…"
EASA	AMC 25.255 Amdt. 27	Amount of Out-of-trim Required – paragraph 1.1 "The equivalent degree of trim"
FAA	AC 25-7D	10.3.2.1.1 "Section 25.255(a)(1)"
FAA	14 CFR 25.1309	Equipment, systems and installations – requirement (c) "Information concerning unsafe system operating conditions…"
EASA	CS 25.1309	Equipment, systems and installations – requirement (c) "Information concerning unsafe system operating conditions…"
FAA	AC 25.1309-1	All
EASA	AMC 25.1309 Amdt.27	Section 9 "Compliance with CS 25.1309" – item (c) "Compliance with CS 25.1309(c)." – paragraph (3) "In the case of aeroplane conditions requiring immediate crew action…"
FAA	AC 25.1302-1	Section 4-2 "Scope of the Flightdeck Certification Program"
EASA	AMC 25.1302 Amdt. 27	Section 4.1 "Scope of the flight deck certification programme"
FAA	AC 25.1329-1C	All
EASA	AMC 25.1329 Amdt. 27	All

Original Recommendations Informing the GAMA Recommendation(s)

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- 7-29
- 7-65
- 7-86
- 9-1
- 9-2
- 9-4

4.11 AFM, FCOM, FCTM

GAMA Recommendation #15
The FAA should consider updated AC 25.1581-1 to include criteria used to determine the content to be included in the AFM, FCOM, and FCTM and identify the relevant stakeholders that should be included within the review on the content included.

Recommendation Context

AFM content is covered within 14 CFR 25.1581 and AC 25.1581-1. AC 25.1581-1 also includes high-level information on the AFM release process but does not specify what disciplines should be included within the authoring, revision, and release processes. The GAMA FDHFWG recommends that AC 25.1581-1 be revised to specify the applicant and Regulator disciplines (e.g., certification, operations, maintenance, and engineering, HF, and other relevant disciplines) that should be included for all Airplane Flight Manual (AFM) and associated Aircraft Operational Manuals (AOM or Flight Crew Operational Manual (FCOM), and Flight Crew Training Manual (FCTM) authoring, modifications, and reviews prior to release and for subsequent revisions. AC 25.1581-1 should clarify that all reviewers need to agree prior to the original release and any subsequent revisions to the AFM and associated AOM or FCOM, and FCTM.

Existing Guidance and Industry Standards

Authority, Organization	Regulations, Guidelines, and Industry Standards	Paragraphs
FAA	14 CFR 25.1581	All

Original Recommendations Informing the GAMA Recommendation

- 7-55

Appendix A. Glossary

Term	Definition
Applicant	Applicant for a Type Certificate, Amended Type Certificate (typically an OEM) or Supplement Type Certificate (typically an OEM or a supplier)
Authority	Certification Authority (e.g., EASA, FAA, or TCCA)
Industry	Industry Group (e.g., GAMA, RTCA, or SAE)

Appendix B. Full List of Original Recommendations Reviewed

The original recommendations, pulled from the reports listed in Section 2, were assessed as “in-scope” or “out-of-scope” in the perspective of its applicability to human factors and industry or regulator. “In-scope” recommendations resulted in at least one GAMA FDWFWG recommendation. “Out-of-scope” recommendations did not result in a GAMA FDHFWG recommendation and are justified in table below.

ID	Recommendation	In-scope/ Out-of-scope
1-1	(b) PILOT RESPONSE TIME.—" the Administrator may not issue a new or amended type certificate for an airplane described in subsection (a) unless the applicant for such certificate has demonstrated to the Administrator that the applicant has accounted for realistic assumptions regarding the time for pilot responses to non-normal conditions in designing the systems and instrumentation of such airplane.	In-scope
1-2	Aircraft Certification Process. FAA shall: "(A) conduct an evaluation of the development of tools and methods to support the integration of human factors assessment and system safety assessments of human interaction with flight deck and flight control systems for transport airplanes into the aircraft certification process under section 44704 of title 49, United States Code; and"	In-scope
1-3	Aircraft Certification Process. FAA shall:"(B) develop a framework to better integrate human factors throughout such aircraft certification process with the objective of improving safety by designing systems and training pilots in a manner that accounts for contemporary knowledge to reduce the possibility of an accident resulting in whole or in part from the pilot’s interaction with the aircraft."	In-scope
1-4	"IN GENERAL. The Administrator shall develop a human factors education program that addresses the effects of modern flight deck systems, including automated systems, on human performance for transport airplanes and the approaches for better integration of human factors in aircraft design and certification. " Target audiance: "(A) Appropriate employees within the Flight Standards Service. (B) Appropriate employees within the Aircraft Certification Service. (C) Other employees or authorized representatives determined to be necessary by the Administrator.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
1-5	Administrator shall require an applicant: (A) perform a system safety assessment with respect to each proposed design change that the Administrator determines is significant, with such assessment considering the airplane-level effects of individual errors, malfunctions, or failures and realistic pilot response times to such errors, malfunctions, or failures related to such change;	In-scope
1-6	Administrator shall require an applicant: "(E) a system safety assessment with respect to a system described in subparagraph (A) or (B) or with respect to any component or other system for which failure or erroneous operation of such component or system could result in an outcome with a severity level of hazardous or catastrophic, as defined in the appropriate Administration airworthiness requirements and guidance applicable to transport-category aircraft defining risk severity.	In-scope
1-7	Assumptions shall be based on test data, analysis or other technical validation methods accounting for a generally accepted consensus among human factors experts regarding realistic pilot response time ACSAA-19-a.1, ACSAA-19-a.3]	In-scope (similar to 1-1)
1-8	FAA, in consultation with industry stakeholders and government agencies, to develop a research plan to address the integration of human factors in the process of designing and certifying transport aircraft. ACSAA-26.0	In-scope (similar to 1-2)
1-9	Calls for the development of tools to validate assumptions about pilot recognition and response to failure indications. ACSAA-26.0	In-scope (similar to 9-3)
1-10	Requires an expert safety review of pilot response assumptions relied upon by FAA and Boeing, including a review of domestic and international manual flying skills. ACSAA-19-c.1	In-scope (similar to 9-3)
2-1	Multiple independent whistleblowers contacted the Committee to allege FAA senior management was complicit in determining the 737 MAX training certification level prior to any evaluation. One whistleblower asserted that they were informed of a phone call by a fellow employee with a senior Flight Standards official in which the official directed the result of the 737 MAX training to be no greater than Level B prior to any testing being conducted.	Out-of-scope (not related to human factors)
2-2	There continues to be debate regarding the various factors and the extent to which each contributed to the crashes, including lack of knowledge of MCAS, sufficiency of pilot training, and level of pilot experience.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
2-3	An example of a human factor is the pilot response time to identify and correct a runaway stabilizer problem. Boeing assumes a reaction time of four seconds for a pilot to identify and begin correcting a runaway stabilizer problem. The 737 MAX Flight Control System Joint Authorities Technical Review (JATR) published in October 2019 includes a review of this assumption as one of its recommendations. Boeing considers this maneuver a memory item and assumes a pilot can recognize and act upon the situation from memory alone in four seconds. 737 MAX Recertification Testing According to a whistleblower who served as an FAA Aviation Safety Inspector in an FAA Certificate Management Office, the long-assumed reaction time described above is not realistic.	In-scope (similar to 1-1)
4-1	Industry & Authority SME evaluation of requirements (eg 25.1302, 25.1322) and related means of compliance to propose updates as appropriate. ARAC human factors WG?	Out-of-scope (internal to regulators)
4-2	Consider “SME panel” process for independent assessment of new/novel certification project activities for appropriate requirements and MoC.	Out-of-scope (internal to regulators)
4-3	Issue 25.1309 rulemaking and related AC’s based on ARAC recommendation. SME WG (eg ARAC system safety WG) to review proposed rule & ACs in consideration of reports and propose updates as appropriate.	Out-of-scope (internal to regulators)
4-4	Development of industry standard for SSA functional hazard assessment methods and validation of assumptions. Review & update ARP4761.	In-scope
4-5	Review of recent version of AC/AMC 21.101 and related FAA training class in consideration of recommendations and propose updates as appropriate CMT working group on changed product rule Industry whitepaper to facilitate understanding of the 21.101 process and importance for continuous improvement in safety of products	In-scope (similar to 6-5, 6-11, 6-12, 6-13, 7-1, 7-2, 7-21 and 7-24)
4-6	Support for FAA resources and funding for appropriate KSAs and training, to include consideration of: Systems engineers and integrated oversight and audit Chief Scientists in areas of technology and innovation such as automation-human interface Project managers for integrated FAA Aircraft Certification and Flight Standards program management for certification and entry into service of aircraft in global environment	Out-of-scope (internal to regulators)
6-1	The FAA should take the necessary steps to ensure a total system approach to safety, linking all safety requirements from type certification to pilot training, and operational performance of the product.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
6-2	The FAA should encourage the integration of Partnership for Safety Plan (PSP), SMS, and ODA activities to create an effective oversight process between manufacturers and FAA to better manage safety and certification issues.	Out-of-scope (internal to regulators)
6-3	The FAA and industry should review requirements and guidance materials to promote more consistent use of systematic analysis of Human Performance and Error Assessments to complement SSAs in aircraft certification.	In-scope
6-4	The FAA should consider removing exclusions for skill-related errors associated with manual control of the airplane and ensure crew interaction with automated systems active in manual flight are systematically assessed.	In-scope (GAMA FDHFWG does not agree with this recommendation)
6-5	Current guidelines recommend that human factors be considered when the system is new or novel, complex and/or integrated. In the future, the FAA should enhance standards to ensure that systematic human factor analyses are conducted for all safety-critical functions and failure modes associated with a change under the changed product rule (14 CFR 21.101).	In-scope
6-6	Test and evaluation should include multiple failure mode scenarios and involve trained pilots who reflect the anticipated end-users of the product.	In-scope
6-7	Resulting data [from test and evaluation] should be fed back into the overall safety assessment of the total system.	In-scope
6-8	Test and evaluation should include multiple failure mode scenarios and involve trained pilots who reflect the anticipated end-users of the product. Resulting data should be fed back into the overall safety assessment of the total system. Significant changes to safety assumptions or performance levels should be tracked.	In-scope
6-9	A summary document explaining SSA assumptions and conclusions relevant to safe operation should be communicated throughout the development process and to end users of the product as reference data for an operator's SMS program. End users should be required to monitor leading indicators to validate the assumptions of the SSA once the product enters service.	In-scope

ID	Recommendation	In-scope/ Out-of-scope
6-10	The FAA should review and clarify the roles and responsibilities of the Aircraft Evaluation Group (AEG) in the product certification process to define objectives, precise engagement, and timing throughout the process. This process should include a review of the working relationship between AFX and AIR to ensure that AEG representatives are engaged early enough in the certification process to review operational safety requirements and oversee assessments of design features and assumptions affecting operations. The AEG should have sufficient engagement throughout the process to be aware of any design changes that occur after the first certification plan is executed. Clarifications should be reflected in policy and guidance materials, which should also be evaluated to determine which organizations should be responsible for them.	Out-of-scope (internal to regulators)
6-11	The FAA should work to ensure FAA policy and guidance are updated to include cross-system (equipment, human, and environment) evaluation of changes.	In-scope (similar to 4-5, 6-5, 6-12, 6-13, 7-1, 7-2, 7-21 and 7-24)
6-12	The FAA should update existing guidance to highlight the vulnerabilities that can develop around multiple adaptations of existing systems, where transfer of historical assumptions may not be appropriate or may require specific validation. This can be relevant to new TC programs, but is more likely relevant to amended TC programs where system integration can have unique challenges.	In-scope (similar to 4-5, 6-5, 6-11, 6-13, 7-1, 7-2, 7-21 and 7-24)
6-13	The FAA should clarify roles and responsibilities of the applicant and FAA in assessing cross-functional interface assumptions in determining what constitutes a significant change. Finding: The FAA evaluates an application for an amended type certificate using the same structured process as for a new type certificate, and both processes result in certification of a safe product. In fact, the ability to change a TC is important and promotes an increase in safety for derivative models that replace aging airplanes.	In-scope (similar to 4-5, 6-5, 6-11, 6-12, 7-1, 7-2, 7-21 and 7-24)
6-14	That the FAA undertake a review to update 14 CFR part 21 certification procedures to reflect a system safety approach to product certification processes and oversight of industry design organizations. This review should include consideration of minimum qualification and organizational requirements for design approval applicants and holders, including responsibilities and privileges such as implementation of compliance assurance and safety management systems consistent with the Certified Design Organization (CDO) concept (Ref ACPRR, 21SMS-ARC, SOC-ARC).	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
6-15	That the FAA should develop comprehensive implementation plans for certification process improvement initiatives that address: people (knowledge, skills, and abilities [KSA], roles/responsibilities, and culture change). (Ref ACPRR, SOC-ARC)	Out-of-scope (internal to regulators)
7-1	Recommendation R1 Based on the JATR team's observations and findings related to the application of the Changed Product Rule to the certification of the flight control system of the B737 MAX, JATR team members recommend that the FAA work with other civil aviation authorities to revise the harmonized approach to the certification of changed products. Changed Product Rules (e.g., 14 CFR §§ 21.19 & 21.101) and associated guidance (e.g., Advisory Circular 21.101-1B and FAA Orders 8110.4C and 8110.48A) should be revised to require a top-down approach whereby every change is evaluated from an integrated whole aircraft system perspective. These revisions should include criteria for determining when core attributes of an existing transport category aircraft design make it incapable of supporting the safety advancements introduced by the latest regulations and should drive a design change or a need for a new type certificate. The aircraft system includes the aircraft itself with all its subsystems, the flight crew, and the maintenance crew. These Changed Product Rule revisions should take into consideration the following key principles: • A comprehensive integrated system-level analysis recognizing that in this complex interactive system, every change could interact with other parts of the system. • The assessment of proposed design changes on existing systems at the aircraft level includes using development assurance principles, system safety principles, and validation & verification techniques. The level of assessment should be proportional to the impact of the change at the aircraft level. • The consideration of training and qualification of flight and maintenance personnel, as well as detailed explicit procedures for the safe operation of the aircraft.	In-scope

ID	Recommendation	In-scope/ Out-of-scope
7-2	Recommendation R1.1: The FAA, in collaboration with other CAAs, should: (a) Revise the harmonized approach to certifying changed products to achieve the expectations of a top-down approach intended by 14 CFR 21.101, where every change is evaluated from an integrated, whole aircraft/human system engineering perspective and where the whole aircraft is assumed affected by the change(s) until substantiated otherwise. This approach should focus on a safe design that as a by-product leads to compliance with regulatory requirements. (b) Develop criteria for determining when core attributes of an existing design make it incapable of supporting the safety advancements introduced by the latest regulations and therefore warrant consideration of a design change and/or certification under a new type certificate. (c) Expand the guidance as to what constitutes a substantial change and what can be considered as only a significant change to address such aspects as changes in software, changes in the roles and responsibilities of the flight crew, and changes to maintenance practices.	In-scope
7-3	Recommendation R1.2: The FAA, in collaboration with other CAAs, should expand the certification process to include “change, areas affected by the change, and areas affecting a change.” This expansion should allow for the identification of interactions such as the one between the AOA system and MCAS in the case of the B737 MAX.	Out-of-scope (internal to regulators)
7-4	Recommendation R1.3: The FAA should implement mandatory aircraft-level reviews along the certification process. These reviews should require risk and failure analyses at the integrated aircraft system-level including the flight crew. (Finding F1.3-A: The certification process is focused on a large number of small details which may minimize the opportunity for a “big picture” view.)	In-scope
7-5	Recommendation R1.6: The FAA should develop processes for identifying perceptions of vagueness and ambiguity in its guidance and strive to clarify all certification guidance that is deemed vague or incomplete.	Out-of-scope (internal to regulators)
7-6	Recommendation R1.7: The FAA and applicants should develop, validate, and implement analytical tools appropriate for the analysis of complex systems.	In-scope (similar to 1-2)

ID	Recommendation	In-scope/ Out-of-scope
7-7	Recommendation R2 Based on the JATR team's observations and findings related to the regulations, policy, and compliance methods applied to the B737 MAX, JATR team members recommend that the FAA update regulations and guidance that are out of date and update certification procedures to ensure that the applied requirements, issue papers, means of compliance, and policies fully address the safety issues related to state-of-the-art designs employed on new projects. JATR team members also recommend that the FAA review its processes to ensure that regulations and guidance materials are kept up to date.	Out-of-scope (internal to regulators)
7-8	Recommendation R2.1: The FAA should review the scope of 14 CFR 25.1302 (Installed Systems and Equipment for Use by the Flightcrew) applicability and clearly define in the TCDS the approach taken for certification.	Out-of-scope (internal to regulators)
7-9	Recommendation R2.2: The FAA should update AC 25.1302-1, Installed Systems and Equipment for Use by the Flightcrew, to clarify the acceptability (or not) of using 14 CFR 25.1302 in changed areas. o Observation O2.2-A: The application of § 25.1302 to areas of change is not explicitly described in its associated guidance material, AC 25.1302-1. The intent of § 25.1302 is stated as follows in its introductory paragraph: This section applies to installed systems and equipment intended for flightcrew members' use in operating the airplane from their normally seated positions on the flight deck. The applicant must show that these 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. o Finding F2.2-A: The JATR team's assessment is that the design and evaluation aspects should be considered for the whole of the cockpit environment, and not to components in isolation.	In-scope

ID	Recommendation	In-scope/ Out-of-scope
7-10	Recommendation R2.3: The FAA should expedite a rule change to 14 CFR 25.1309 (Equipment, Systems, and Installations) and its associated means of compliance in order to implement the recommendations stemming from the Aviation Rulemaking Advisory Committee (ARAC) Systems Design and Analysis Harmonization Working Group (SDAHWG) (2001). This action is necessary to minimize the possibility of applicants using old guidance that is not fully effective for the system development and for conducting SSA in the context of increased system complexity and interactions. Finding F2.3-A: Although the certification basis for § 25.1309 was updated for the latest amendment per Changed Product Rule analysis, delayed FAA rulemaking for updating § 25.1309 and related guidance according to the recommendations of the ARAC SDAHWG allows applicants to use geriatric guidance for safety assessment demonstration.	In-scope
7-11	Recommendation R2.7: If any flight control surface is used in a novel manner, the FAA should be directly involved. The FAA should assess the need for an issue paper for development of acceptable means of compliance with existing regulations, or develop special conditions if the regulations do not contain adequate or appropriate safety standards.	Out-of-scope (internal to regulators)

7-12	Recommendation R2.8: The FAA should establish appropriate pilot recognition times and reaction times, based on substantive scientific studies which take into account the operational environment, the circumstances under which malfunctions may occur, and the effect of surprise. Observation O2.8-A: FAA guidance for test flights in AC 25-7D, Flight Test Guide for Certification of Transport Category Airplanes, and AC 25.1329-1C, Approval of Flight Guidance Systems, require test pilots to delay initiation of response to flight control or flight guidance malfunctions to account for pilot recognition time and pilot reaction time. Often, recognition time is assumed to be 1 second, and reaction time is assumed to be 3 seconds. Thus, test pilots are told that “Recovery action should not be initiated until 3 seconds after the recognition point” (AC 25.1329-1C). o Observation O2.8-B: The current guidance recognizes that pilot recognition time may depend on various factors including the nature of the failure, but applicants are only required to prepare specific justification of their assumed recognition time if it is less than 1 second. o Observation O2.8-C: Although the above guidance is aimed at test pilots conducting test flights, applicants seem to use this guidance as a design assumption that the pilot will be able to respond correctly within 4 seconds of the occurrence of a malfunction. For example, in the case of the B737 MAX, it was assumed that, since MCAS activation rate is 0.27 degrees of horizontal stabilizer movement per second, during the 4 seconds that it would take a pilot to respond to an erroneous activation, the stabilizer will only move a little over 1 degree, which should not create a problem for the pilot to overcome. o Observation O2.8-D: No studies were found that substantiate the FAA guidance concerning pilot recognition time and pilot reaction time. o Observation O2.8-E: Several FAA studies with general aviation pilots demonstrate that these general aviation pilots may take many seconds, and in some cases many minutes, to recognize and respond to malfunctions (e.g., DOT/FAA/AM-97/24; DOT/FAA/AM-02/19; DOT/FAA/AM-05/23). o Observation O2.8-F: A NASA study of abnormal flight events with qualified, current, and active airline pilots also found substantially longer recognition times and reactions times, even in the case of expected events, than the times given in AC 25-7D and AC 25.1329-1C. o Observation O2.8-G: Analysis of aviation accidents demonstrates that pilots may take a significantly longer time to recognize a malfunction and respond to it than the test flight guidance suggests. For example, the NTSB states:	In-scope

ID	Recommendation	In-scope/ Out-of-scope
	"When a flight crew is confronted with a sudden, abnormal event, responses are more likely to be delayed or inappropriate." (NTSB/AAR-14/01) o Observation O2.8-H: Modern aircraft can have subtle failure modes that may take substantial amounts of time to be recognized. Furthermore, automation can mask some failures and significantly delay the possibility for the pilot to recognize the malfunction. o Finding F2.8-A: It is not clear on what the FAA guidance concerning pilot recognition time and pilot reaction time is based. Finding F2.8-B: Pilot recognition time and reaction time to a malfunction may depend on the particular nature of the malfunction, the circumstances under which it occurs, the corrective action required, and the individual pilot. o Finding F2.8-C: There is a substantial difference between the situation of a test pilot who is testing a particular malfunction with precise foreknowledge of the malfunction to be tested and the proper response to be initiated, and the situation of a line pilot on a routine revenue flight who is not expecting any malfunction. Thus, guidance that is relevant to test flights may not be appropriate for routine revenue flights. o Finding F2.8-D: The 3-second reaction time assumption dates back decades, to where the performance of the autopilot was constantly monitored by the crew in flight (e.g., guidance given in AC 25.1329-1A, Automatic Pilot Systems Approval, dated July 8, 1968). However, with increasing reliability and advances in flight deck alerting and displays, it may no longer be appropriate to assume that the pilot flying will be monitoring the automation as closely as in the past. o Finding F2.8-E: The FAA's guidance concerning pilot reaction time of 3 seconds may not be appropriate given current aircraft technology and the current operational environment. o Finding F2.8-F: Although current guidance seems to recognize potential variability in pilot recognition time, it is not clear that applicants are following the spirit of that guidance, because only recognition times of less than 1 second must be formally justified.	
7-13	Recommendation R2.9: The FAA should require applicants to provide validated and justified pilot recognition and reaction times for any given failure, with consideration of all associated flight deck effects within the expected operational environment.	In-scope (similar to 1-1)

7-14	Recommendation R2.10: The FAA should provide guidance to test pilots to initiate recovery action only once the combined recognition time and reaction time validated for the given failure being tested have elapsed. Observation O2.8-A: FAA guidance for test flights in AC 25-7D, Flight Test Guide for Certification of Transport Category Airplanes, and AC 25.1329-1C, Approval of Flight Guidance Systems, require test pilots to delay initiation of response to flight control or flight guidance malfunctions to account for pilot recognition time and pilot reaction time. Often, recognition time is assumed to be 1 second, and reaction time is assumed to be 3 seconds. Thus, test pilots are told that “Recovery action should not be initiated until 3 seconds after the recognition point” (AC 25.1329-1C). o Observation O2.8-B: The current guidance recognizes that pilot recognition time may depend on various factors including the nature of the failure, but applicants are only required to prepare specific justification of their assumed recognition time if it is less than 1 second. o Observation O2.8-C: Although the above guidance is aimed at test pilots conducting test flights, applicants seem to use this guidance as a design assumption that the pilot will be able to respond correctly within 4 seconds of the occurrence of a malfunction. For example, in the case of the B737 MAX, it was assumed that, since MCAS activation rate is 0.27 degrees of horizontal stabilizer movement per second, during the 4 seconds that it would take a pilot to respond to an erroneous activation, the stabilizer will only move a little over 1 degree, which should not create a problem for the pilot to overcome. o Observation O2.8-D: No studies were found that substantiate the FAA guidance concerning pilot recognition time and pilot reaction time o Observation O2.8-E: Several FAA studies with general aviation pilots demonstrate that these general aviation pilots may take many seconds, and insome cases many minutes, to recognize and respond to malfunctions (e.g., DOT/FAA/AM-97/24; DOT/FAA/AM-02/19; DOT/FAA/AM-05/23). o Observation O2.8-F: A NASA study of abnormal flight events with qualified, current, and active airline pilots also found substantially longer recognition times and reactions times, even in the case of expected events, than the times given in AC 25-7D and AC 25.1329-1C. o Observation O2.8-G: Analysis of aviation accidents demonstrates that pilots may take a significantly longer time to recognize a malfunction and respond to it than the test flight guidance suggests. For example, the NTSB states: “When a flight crew is confronted with a sudden, abnormal event, responses are more likely to be delayed or inappropriate.” (NTSB/AAR-14/01)	In-scope

ID	Recommendation	In-scope/ Out-of-scope
	o Observation O2.8-H: Modern aircraft can have subtle failure modes that may take substantial amounts of time to be recognized. Furthermore, automation can mask some failures and significantly delay the possibility for the pilot to recognize the malfunction. o Finding F2.8-A: It is not clear on what the FAA guidance concerning pilot recognition time and pilot reaction time is based. o Finding F2.8-B: Pilot recognition time and reaction time to a malfunction may depend on the particular nature of the malfunction, the circumstances under which it occurs, the corrective action required, and the individual pilot. o Finding F2.8-C: There is a substantial difference between the situation of a test pilot who is testing a particular malfunction with precise foreknowledge of the malfunction to be tested and the proper response to be initiated, and the situation of a line pilot on a routine revenue flight who is not expecting any malfunction. Thus, guidance that is relevant to test flights may not be appropriate for routine revenue flights. o Finding F2.8-D: The 3-second reaction time assumption dates back decades, to where the performance of the autopilot was constantly monitored by the crew in flight (e.g., guidance given in AC 25.1329-1A, Automatic Pilot Systems Approval, dated July 8, 1968). However, with increasing reliability and advances in flight deck alerting and displays, it may no longer be appropriate to assume that the pilot flying will be monitoring the automation as closely as in the past o Finding F2.8-E: The FAA's guidance concerning pilot reaction time of 3 seconds may not be appropriate given current aircraft technology and the current operational environment. o Finding F2.8-F: Although current guidance seems to recognize potential variability in pilot recognition time, it is not clear that applicants are following the spirit of that guidance, because only recognition times of less than 1 second must be formally justified.	

ID	Recommendation	In-scope/ Out-of-scope
7-15	Recommendation R3.8: The FAA should review the prescriptive use of 3 seconds under 14 CFR 25.255 (Out-of-Trim Characteristics) for the evaluation of mis-trim conditions, especially for automatic trim systems where pilot recognition is relied upon to detect and arrest runaway failures. The rate of trim used by these automatic systems should also be considered in showing compliance to § 25.255. o Observation O3.8-A: Out-of-trim characteristics, per the requirements of § 25.255, were found acceptable for a 0.6 unit nose-down out-of-trim condition. This out-of-trim value was determined by 3 seconds of trim input at the flaps-up main electric stabilizer trim rate of 0.2 degrees per second, which is greater than the autopilot trim rate. o Observation O3.8-B: The higher MCAS trim rate of 0.27 degrees per second was not selected for the demonstration of compliance with § 25.255, even though failures could result in un-commanded stabilizer trim movement at this rate. o Finding F3.8-A: Section 25.255 applies to jet upset events and uses a prescriptive 3 seconds as the amount of out-of-trim that could occur before pilot reaction. For automatic trim systems, the 3-second reaction time may not be appropriate, depending on the cockpit alerting philosophy and trim system architecture and controls.	In-scope
7-16	Recommendation R3.9: The FAA should review the AFM procedure for stabilizer runaway and ensure that adequate emphasis is placed on the importance of using main electric stabilizer trim to return to a trimmed state. Crew error should be considered in the event that aisle stand stabilizer cutout switches are used before returning to trim conditions. Finding F3.9-A: Certain stabilizer runaway failures may generate significant out-of-trim conditions. Main electric stabilizer trim is considered the primary means to stop runaway stabilizer in Boeing's assumptions and validation tests. The degree of stabilizer mis-trim and resulting transient from steady-state flight may result in hazardous or even catastrophic failure conditions.	Out-of-scope (specific for Boeing)
7-17	Recommendation R3.10: The FAA should review the Boeing assumption of a 4-second pilot reaction time to stabilizer runaway failures to ensure that a conservative value is used, since pilot action is required to counter these failures.	Out-of-scope (specific for Boeing)
7-18	Recommendation R3.11: For failure of the STS, the FAA should consider the requirement to alert flight crews to the reduction in safety margins due to the absence of the stability augmentation function provided by the system. Consideration should be given to AFM flight envelope limitations or warning/caution statements, if required.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
7-19	Recommendation R3.13: The FAA should ensure that simulation devices that are used for certification credit have the required level of fidelity for the associated test. Observation O3.13-A: During evaluation in the Boeing engineering simulator (ECab), the JATR team observed that the device does not incorporate control loading on the manual stabilizer trim wheel. As a result, control forces on the manual stabilizer trim wheel are not representative of the aircraft	Out-of-scope (specific for Boeing)
7-20	Recommendation R3.17: The FAA should review the compliance details of the optional head-up display (HUD) approved under STC on the B737 MAX and determine if its alerting meets regulatory requirements.	Out-of-scope (internal to regulators)
7-21	Recommendation R4 Based on the JATR team's observations and findings related to the FAA type certification process, JATR team members recommend that the FAA review and update the regulatory guidance pertaining to the type certification process with particular emphasis on early FAA involvement to ensure the FAA is aware of all design assumptions, the aircraft design, and all changes to the design in cases where a changed product process is used. The FAA should consider adding feedback paths in the process to ensure that compliance, system safety, and flight deck/human factors aspects are considered for the aircraft design throughout its development and certification.	In-scope
7-22	Recommendation R4.1: The FAA should consider defining objective criteria for FAA familiarization with design details and FAA involvement in compliance findings, to be applied initially and all along the certification process, when development and certification prompt design or compliance method revision.	Out-of-scope (internal to regulators)
7-23	Recommendation R4.2: The FAA should consider developing policy or standards to be followed by applicants on proper visibility, clarity, and consistency of key design and compliance information that is submitted for certification, particularly with new design features.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
7-24	Recommendation R4.3: The FAA should implement policy or further guidance that emphasizes the need for early coordination with the certification authority for the FHA validation and PSSA review to ensure the proposed system architecture can reasonably meet the FHA safety requirements. In addition, the FAA should emphasize that early involvement with the certification authority is recommended for design changes. Finding F4.3-A: The FAA certification process resulted in FHA/ PSSA information being submitted much too late (at type inspection authorization) for the FAA to have any influence on the proposed MCAS design for the purpose of demonstrating compliance. The FHA information that is delivered to the FAA is the FHA summary. Therefore, the FAA does not have the details of the analysis, which are documented in Boeing's internal coordination sheets (including important FHA assumptions). FAA's visibility into important system safety information was therefore incomplete and fragmented.	In-scope
7-25	Recommendation R4.4: The FAA should refuse to accept function descriptions that are fragmented among several documents.	Out-of-scope (internal to regulators)
7-26	Recommendation R4.5: The FAA should require applicants to highlight and properly describe any functional change at the earliest stage possible in the certification process regardless of the preliminary functional hazard classification.	Out-of-scope (internal to regulators)
7-27	Recommendation R4.6: The FAA should ensure applicants maintain records of interactions with certification authorities, especially if those interactions lead to agreements affecting documentation and certification deliverables.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
7-28	Recommendation R6.1: The FAA should ensure applicants improve adherence to fail-safe design concept principles when designing or modifying systems. The FAA should encourage applicants not to design only for compliance, but also to follow basic principles to design for safety when developing or changing system functions. This should include elimination of hazards and use of design features, warnings, and procedures. o Observation O6.1-A: Proper flight crew action was considered an adequate mitigation to risks such as erroneous activation of MCAS. o Finding F6.1-A: The JATR team identified that the design process was not sufficient to identify all the potential MCAS hazards. As part of the single channel speed trim system, the MCAS function did not include fault tolerant features, such as sensors voting or limits of authority, to limit failure effects consistent with the hazard classification. o Finding F6.1-B: The use of pilot action as a primary mitigation means for MCAS hazards, before considering eliminating such hazards or providing design features or warnings to mitigate them, is not in accordance with Boeing's process instructions for safe design in the conception of MCAS for the B737 MAX. o Finding F6.1-C: The JATR team found that there was a missed opportunity to further improve the system design through the use of available fail-safe design principles and techniques presented in AC 25.1309-1A and in EASA AMC 25.1309 in the MCAS design.	In-scope

ID	Recommendation	In-scope/ Out-of-scope
7-29	Recommendation R6.2: As part of the certification process for transport category airplanes, the FAA should examine all "major hazards" where a key mitigation is flight crew action to see if they are potentially catastrophic. The FAA should evaluate the impact of the hazard and its mitigations at the aircraft level, including the impact on the crew and cockpit environment, to determine if additional mitigating design features are required. o Observation O6.1-A: Proper flight crew action was considered an adequate mitigation to risks such as erroneous activation of MCAS. o Finding F6.1-A: The JATR team identified that the design process was not sufficient to identify all the potential MCAS hazards. As part of the single channel speed trim system, the MCAS function did not include fault tolerant features, such as sensors voting or limits of authority, to limit failure effects consistent with the hazard classification. o Finding F6.1-B: The use of pilot action as a primary mitigation means for MCAS hazards, before considering eliminating such hazards or providing design features or warnings to mitigate them, is not in accordance with Boeing's process instructions for safe design in the conception of MCAS for the B737 MAX. o Finding F6.1-C: The JATR team found that there was a missed opportunity to further improve the system design through the use of available fail-safe design principles and techniques presented in AC 25.1309-1A and in EASA AMC 25.1309 in the MCAS design.	In-scope
7-31	Recommendation R6.4: The FAA should implement policies and further guidance to reinforce that workload evaluations should not be limited to the areas affected by the design changes alone. Workload evaluation should be performed with the complete flight deck effects of the failure conditions, including associated procedures. o Finding F6.4-A: When all flight deck effects are considered, the introduction of the MCAS function invalidated aircraft-level assumptions for flight crew responses related to erroneous AOA failures under certain conditions. A complete workload assessment was not performed for validation of the erroneous AOA effects with the added MCAS functionality. The same assumptions for flight crew responses to erroneous AOA were carried over from previous programs without formal validation.	In-scope

ID	Recommendation	In-scope/ Out-of-scope
7-32	Recommendation R6.5: The FAA should emphasize the need to perform a functional SSA. The complete system function, including interfaces and unchanged parts of the implementation, should be assessed. When adding new functions, a complete top-down safety assessment process from the aircraft level should be performed. Special emphasis should be given on exercising care for reuse of safety assessment analysis information.	Out-of-scope (specific for Safety Process)
7-33	Recommendation R6.6: The FAA should ensure that when new functions are introduced, the applicants develop a new FHA specific to that function that is used to develop design mitigations for identified hazards.	Out-of-scope (specific for Safety Process)
7-35	Recommendation R6.7: Such system safety function should ensure that comprehensive and integrated risk, failure, and safety analyses are performed any time a design change is made that could affect the safe operation of the aircraft. Adoption of a safety management system is one way this can be achieved.	Out-of-scope (internal to regulators)
7-36	Recommendation R6.8: Given the importance of the single & multiple failure (S&MF) analysis or equivalent in the development assurance process, the FAA should require the S&MF analysis or equivalent as a certification deliverable to demonstrate system-level integration and the effects of cascading hazards at the aircraft level.	Out-of-scope (internal to regulators)
7-37	Recommendation R6.9: The FAA should not accept analysis of a single “worst-case scenario” as covering all possible failure modes of the related systems. The FAA should require applicants to analyze each function to identify failure modes for each signal input considering all foreseeable scenarios and the multiple possible outcomes for each flight phase in their cascading effects analysis.	Out-of-scope (internal to regulators)
7-38	Recommendation R6.10: The FAA should not accept a mitigation for the single “worst-case scenario” as mitigating all possible scenarios. The FAA should ensure that mitigations are developed as appropriate for the multiple outcomes identified in the cascading effects analysis.	Out-of-scope (internal to regulators)
7-39	Recommendation R7 Based on the JATR team’s observations and findings related to human factors-related issues in the certification process, JATR team members recommend that the FAA integrate and emphasize human factors and human system integration throughout its certification process.	In-scope

ID	Recommendation	In-scope/ Out-of-scope
7-40	Recommendation R7 Human factors-relevant policies and guidance should be expanded and clarified, and compliance with such regulatory requirements as 14 CFR §§ 25.1302 (Installed Systems and Equipment for Use by the Flightcrew), 25.1309 (Equipment, Systems, and Installations), and 25.1322 (Flightcrew Alerting) should be thoroughly verified and documented.	Out-of-scope (internal to regulators)
7-41	Recommendation R7 To enable the thorough analysis and verification of compliance, the FAA should expand its aircraft certification resources in human factors and in human system integration.	Out-of-scope (internal to regulators)
7-42	Recommendation R7.2: The FAA should review existing guidance material and update as necessary to emphasize the importance of human factors and human system integration throughout the certification process. o Observation O7.2-A: Existing human factors guidance material (e.g., AC 25- 1302-1) may be insufficient to emphasize the importance of human factors and human system integration throughout the certification process. (See also Observations O2.1-A and O2.2-A and Findings F2.2-A and F6.4-A)	In-scope (similar to 7-39)
7-43	Recommendation R8 Based on the JATR team's observations and findings related to the development assurance process applied to the design of the flight control system of the B737 MAX, JATR team members recommend that the FAA ensure applicants apply industry best practice for development assurance, including requirements management, visibility of assumptions, process assurance activities, and configuration management. The FAA should ensure achievement of the close coupling that is required between the applicant safety analysis process and the development assurance process to classify failure conditions and derive the level of rigor of design development and verification. A current example of industry best practice is SAE International's Aerospace Recommended Practice 4754 (ARP4754). The FAA should review and amend Advisory Circular 20-174 to clearly articulate the principles of ARP4754, promoting industry best practice for development assurance of aircraft and aircraft systems to address applicants' design trend of increasing integration between aircraft functions and systems.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
7-44	Recommendation R8.7: To the extent applicants rely on original aircraft- and system- level assumptions, the FAA should ensure the applicants perform a thorough review of system design changes to ensure they are not inconsistent with those assumptions. o Finding F6.4-A: When all flight deck effects are considered, the introduction of the MCAS function invalidated aircraft-level assumptions for flight crew responses related to erroneous AOA failures under certain conditions. A complete workload assessment was not performed for validation of the erroneous AOA effects with the added MCAS functionality. The same assumptions for flight crew responses to erroneous AOA were carried over from previous programs without formal validation.	In-scope
7-45	Recommendation R8.8: The FAA should emphasize in guidance that, besides requirements-based testing, the applicant should perform robustness test cases for identifying and investigating unexpected system effects and flight crew responses. For example, the process should account for evaluation of cases where pilots do not follow the assumptions (e.g., not trimming out the failure). o Finding F6.4-A: When all flight deck effects are considered, the introduction of the MCAS function invalidated aircraft-level assumptions for flight crew responses related to erroneous AOA failures under certain conditions. A complete workload assessment was not performed for validation of the erroneous AOA effects with the added MCAS functionality. The same assumptions for flight crew responses to erroneous AOA were carried over from previous programs without formal validation.	In-scope

ID	Recommendation	In-scope/ Out-of-scope
7-46	Recommendation R8.9: The FAA should develop, validate, and implement design and analysis models, methodologies, and approaches capable of identifying interactions among systems such as the catastrophic interaction between the AOA system and MCAS. o Observation O8.9-A: FAA Order 8110.48A, How to Establish the Certification Basis for Changed Aeronautical Products, provides the following guidance in paragraph 2-1: "Essentially, a substantial design change is an alteration to a product that is so extensive that the design models, methodologies, and approaches used to demonstrate a previous compliance finding cannot be used." o Finding F8.9-A: The B737-8 MAX accident scenarios were not identified during the testing and certification process. This is an indication that the "design models, methodologies, and approaches" used to demonstrate compliance need improvement to identify interactions among systems.	Out-of-scope (internal to regulators)
7-47	Recommendation R8.11: The FAA should ensure applicants provide a full list of all aircraft proposed changes (no matter how trivial), complete with a system description and all interfaces associated with each proposed change, such that an informed assessment can be made using established criteria prior to agreeing on the systems which will be subject to limited application of a development assurance process. Finding F8.11-A: The practice of applying a limited application of a development assurance process for modifications to aircraft or systems can be improved – specifically, the criteria used to assess each proposed modification and the requirement to satisfy safety assessment objectives. o Observation O8.11-A: The limited application of a development assurance process agreed between the FAA and Boeing did not adequately establish the criteria for determining which new or modified systems require certification compliance findings relative to development assurance. a) Each candidate system should be critically assessed against a robust set of criteria. b) Criteria should be informed by the objectives and requirements of ARP4754A. c) The FAA should be provided with sufficient insight into the modifications to make an informed assessment of each proposed modification against the established criteria. d) The rationale and decisions resulting from this assessment should be documented.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
7-48	Recommendation R9 Based on the JATR team's findings and observations related to the operational design assumptions of crew response applied during the certification process for the flight control system of the B737 MAX, JATR team members recommend that the FAA require the integration of certification and operational functions during the certification process. The FAA should be provided all system differences between related aircraft in order to adequately evaluate operational impact, systems integration, and human performance.	In-scope
7-49	Recommendation R9.1: The FAA should revise AC 120-53B and FAA Order 8900.1 Volume 8, Chapter 2 to include an assessment of the cumulative effects of changed products, such as differences in aircraft systems, displays, flight characteristics, and procedures. Observation O9.1-A: AC 120-53B does not require the cumulative effects on system changes to be considered. o Observation O9.1-B: Boeing submitted to the FAA's AEG a list of features of the B7378 MAX cockpit which were changed from the base model B737-800. In Issue Paper O-1, Type Rating Determination and 14 CFR Training Requirements, the FAA raised concerns about cumulative effects of system changes from the B737 NG to the B737 MAX that may cause greater than level B differences training. Boeing's response to this concern was that there was no precedent in prior Boeing amended type certification projects and that AC 120-53B did not require the cumulative effects on system changes to be considered. The FAA accepted Boeing's response on 26 January 2016.	In-scope
7-50	Recommendation R9.2: The FAA should review and if necessary, revise AC 120-53B to ensure that the AEG and FSB are provided with all the system differences between related aircraft irrespective of engineering determination of the safety significance.	Out-of-scope (internal to regulators)
7-51	Recommendation R9.3: Where the assessment of the effectiveness of differences training is not conducted in an aircraft, the FAA should require the AEG to use operational flight crew complements (e.g., line captains and line first officers), with a range of flight experience, as part of the assessment.	Out-of-scope (internal to regulators)
7-52	Recommendation R9.4: The AEG should have deeper involvement during the certification process and collaborate closely with FAA's Aircraft Certification Service (AIR) to ensure they have the proper knowledge to make informed decisions about operational suitability issues that may be affected by certification details.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
7-53	Recommendation R9.6: The FAA should review and if necessary revise AC 25.1302-1, Installed Systems and Equipment for Use by the Flightcrew, to ensure that failures of related systems are assessed taking into account human performance and the operational environment utilizing an AEG operational specialist. o Observation O9.6-A: A review of preliminary accident reports KNKT.18.10.35.04 and AI-0/19 indicates that the complex operational environment that faced the flight crews and the associated workload may not have been anticipated in the certification process. o Finding F9.6-A: AC 25.1302-1 does not adequately address the operational aspect of an aircraft's design. o Finding F9.6-B: AC 25.1302-1, paragraph 1-2(a), Applicability, lists a number of certification roles that the guidance is directed toward, and the list does not include an operational pilot specialist such as an aviation safety inspector from the AEG.	In-scope
7-54	Recommendation R9.7: The FAA should review and if necessary, revise guidance material to ensure that operational considerations associated with the design change are adequately risk-assessed to minimise the potential for flight crew error. o Observation O9.6-A: A review of preliminary accident reports KNKT.18.10.35.04 and AI-0/19 indicates that the complex operational environment that faced the flight crews and the associated workload may not have been anticipated in the certification process. o Finding F9.6-A: AC 25.1302-1 does not adequately address the operational aspect of an aircraft's design. o Finding F9.6-B: AC 25.1302-1, paragraph 1-2(a), Applicability, lists a number of certification roles that the guidance is directed toward, and the list does not include an operational pilot specialist such as an aviation safety inspector from the AEG.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
7-55	Recommendation R10.5: The FAA should develop a documented process to determine what information will be included in the AFM, FCOM, and FCTM. The process must include agreement from all disciplines (e.g., certification, operations, maintenance, human factors) for the system or function descriptions to be removed. o Observation O10.5-A: Information related to the MCAS functionality within the FCC originally was in the draft FCOM and was subsequently removed (around the time of MCAS Revision D, in early 2016), but without a formal process in place to ensure agreement from all disciplines on the removal of that information. Technology, even if it functions without pilot involvement, may be integrated with other aircraft systems. One system or functional failure could impact other systems requiring pilot involvement. o Finding F10.5-A: Information related to MCAS functionality and failure scenarios is critical for pilot knowledge and understanding of the system as it interfaces with the aircraft's trim system and AOA inputs.	In-scope
7-57	Recommendation R1.4: The FAA should provide clear definitions of key terms in its guidance for 14 CFR §§ 21.19 and 21.101.	Out-of-scope (internal to regulators)
7-58	Recommendation R1.5: The FAA should define and clearly describe the intent and expected use of an ADRC in available guidance. In addition, the FAA should elaborate on the application of ADRCs in future developments (e.g., future applicant modification and supplemental type certificates (STCs)). The FAA should identify the legal standing that ensures the adherence to ADRCs for future changes.	Out-of-scope (specific for Boeing)
7-59	Recommendation R1.8: The FAA should ensure that the TCDS for the B737 MAX (TCDS No. A16WE) clearly states which part of 14 CFR 25.1322 (Flightcrew Alerting), and at which amendment level, the B737 MAX complies to.	Out-of-scope (internal to regulators)
7-60	Recommendation R1.9: The FAA should ensure that TCDSs accurately reflect when compliance is found at the stated amendment level and when compliance is limited to a subset of the aircraft (such as a change).	Out-of-scope (internal to regulators)
7-62	Recommendation R2.5: Sufficient time and resources should be allocated for the proper treatment of issue papers to avoid inconsistencies and errors.	Out-of-scope (internal to regulators)
7-63	Recommendation R2.6: The FAA should review its internal procedures to emphasize the need for issue papers when the applicant proposes means of compliance that deviates from advisory circulars.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
7-64	Recommendation R3 Based on the JATR team's observations and findings related to the certification of the B737 MAX flight control system and related interfaces, JATR team members recommend that the FAA review the B737 MAX compliance to 14 CFR §§ 25.1329 (Flight Guidance System), 25.1581 (Airplane Flight Manual – General), and 25.201 (Stall Demonstration) and ensure the consistent application and interpretation of regulatory guidance material for the system safety assessment, handling qualities rating method, and conformity requirements for engineering simulators and devices. Should there be a non-compliance, the root cause should be identified and measures implemented to prevent recurrence.	Out-of-scope (internal to regulators)
7-65	Recommendation R3.1: The FAA should ensure early involvement by applicants and the FAA in the establishment of the detailed means of compliance for SSA demonstration (e.g., 14 CFR §§ 25.1309 (Equipment, Systems, and Installations) and 25.671 (Control Systems – General)), especially in case any deviations from standard guidance are planned, or if additional guidance not originally intended for §§ 25.1309 and 25.671 is expected to be part of the compliance demonstration. o Observation O2.6-A: A combination of ACs was used for demonstrating compliance with system safety requirements; no AC/acceptable means of compliance (AMC) was followed in its entirety. The detailed use of the referenced ACs and an indication of which sections are applicable was not formally recorded in any certification document that the JATR team reviewed. o Finding F2.6-A: The use of a combination of partial ACs as means of compliance should have led the FAA to formalize the agreement with this strategy, possibly by means of an AMC issue paper.	In-scope
7-66	Recommendation R3.2: The FAA should issue a policy statement on the need for caution and early negotiation with the certification authority when an applicant proposes using additional guidance not originally intended for showing compliance to system safety requirements.	Out-of-scope (specific for Boeing)

ID	Recommendation	In-scope/ Out-of-scope
7-72	Recommendation R3.12: Because the guidance provided by the HQRM in AC 25-7D is not harmonized, the FAA should determine if continued application of HQRM is appropriate for the evaluation of failure conditions and revise the AC accordingly. o Observation O3.11-A: STS inoperative wind-up turns were completed to 1.6g as part of the B737 MAX certification. STS inoperative stalls were completed to stick shaker + 1 second (approach to stall). The JATR team's assessment is that the limited envelope for evaluation of characteristics for this failure condition does not support the absence of an envelope limitation in the associated nonnormal procedure. o Observation O3.11-B: STS inoperative wind-up turns, flown by Boeing during the course of the JATR, did not show any unsafe characteristics to approximately 2g. o Finding F3.11-A: HQRM guidance from AC 25-7C was applied for the evaluation of control systems malfunctions. The application of the probabilistic aspects of this guidance was appropriate to the determination of the required handling qualities, but may not be suitable for evaluation of the failure condition per AC 25.1309-1A, System Design and Analysis, and AC 25-7C. o Finding F3.11-B: For § 25.1309 compliance, the criticality of the failure condition should account for intensifying conditions, such as crew workload or multiple cockpit indications, and effects and interrelationship of failures with the flight envelopes. o Finding F3.11-C: Boeing's application of HQRM allowed for a reduced envelope in the evaluation of SPEED TRIM FAIL, which may not meet the intent of guidance within AC 25-7C and AC 25-1309-1A.	Out-of-scope (internal to regulators)
7-73	Recommendation R3.14: The FAA should review the B737 MAX's compliance to 14 CFR 25.1581 (Airplane Flight Manual – General) and address the inconsistency between AC 25.1581-1 and 14 CFR §§ 25.1581 thru 25.1587, which outline the required information to be included in the AFM and approved under § 25.1581.	Out-of-scope (specific for Boeing)
7-74	Recommendation R3.15: The FAA should exercise careful oversight and scrutiny of AFM procedures for Boeing aircraft.	Out-of-scope (specific for Boeing)

ID	Recommendation	In-scope/ Out-of-scope
7-76	Recommendation R5 Based on the JATR team's observations and findings related to FAA's oversight by the Boeing Aviation Safety Oversight Office (BASOO), JATR team members recommend that the FAA conduct a workforce review of the BASOO engineer staffing level to ensure there is a sufficient number of experienced specialists to adequately perform certification and oversight duties, commensurate with the extent of work being performed by Boeing. The workforce levels should be such that decisions to retain responsibility for finding compliance are not constrained by a lack of experienced engineers.	Out-of-scope (specific for Boeing)
7-78	Recommendation R5.1: The FAA should identify and implement procedures for increased direct FAA involvement in safety critical areas of ODA certification projects. Safety critical areas may include certain regulations, reports, inspections, tests, or other critical items. Direct involvement may include the FAA retaining approvals, conducting real-time oversight, or implementing other procedures. o Observation O5.1-A: The FAA initially delegated acceptance of approximately 40% of the B737 MAX project's certification plans to the Boeing ODA. Additional certification plans that were originally retained for acceptance by the FAA were later delegated to the Boeing ODA as the certification project progressed. While the JATR team did not conduct an exhaustive review of other ODAs, the team observed that delegating the acceptance of certification plans does not appear to be a widespread practice for the FAA. o Finding F5.1-A: The FAA extensively delegated compliance findings on the B737-8 MAX project to the Boeing ODA. Safety critical areas, including system safety documents related to MCAS, were initially retained by the FAA and then delegated to the Boeing ODA. (See also Findings F4.1-A, F4.1-B, and F4.1-C.) o Finding F5.1-B: The JATR team's belief is that FAA involvement in the certification of MCAS would likely have resulted in design changes that would have improved safety.	Out-of-scope (specific for Boeing)
7-79	Recommendation R5.2: The FAA should conduct a workforce review of the BASOO engineer staffing level to ensure sufficient personnel to adequately perform all assigned duties (including but not limited to: certification document approval, findings of compliance, and ODA oversight).	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
7-84	Recommendation R5.7: The FAA should require Boeing to submit compliance data recommending FAA approval for FAA flight test activities. Compliance data submissions should include FAA Form 8100-9, Statement of Compliance with Airworthiness Standards, signed by the appropriate E-UM recommending approval of the data.	Out-of-scope (specific to Boeing)
7-86	Recommendation R6 Aircraft functions should be assessed, not in an incremental and fragmented manner, but holistically at the aircraft level. System function and performance, including the effects of failures, should be demonstrated and associated assumptions should be challenged to ensure robust designs are realized. The safety analysis process should be integrated with the aircraft development assurance process to ensure all safety requirements and associated assumptions are correct, complete, and verified. The FAA should encourage applicants to have a system safety function that is independent from the design organization, with the authority to impartially assess aircraft safety and influence the aircraft/system design details. Adoption of a safety management system is one way this can be achieved.	In-scope
7-87	Recommendation R6.11: The FAA should require applicants to develop an SSA process description to be followed by each system for consistency of methodology, use of guidance, and assumptions.	Out-of-scope (internal to regulators)
7-88	Recommendation R6.12: The FAA should develop a practice of questioning the validity of assumptions made by the applicant and require substantive support for all such assumptions. o Finding F6.12-A: The JATR observed in Issue Paper G-1 that Boeing's rationale for exceptions from current amendments for the B737 MAX was focused on similarity with the B737 NG model and the risk of confusing the pilots by introducing differences between the two models (e.g., exceptions for § 25.1322). These approaches were driven by Boeing's assumptions that the MAX is a replacement for the NG and that MAX pilots will be experienced NG pilots. These assumptions were not warranted, as demonstrated by airlines for which the MAX was the first B737 model to be purchased (e.g., Air Canada), and by new pilots entering service directly to the MAX (e.g., the First Officer on ET302). o Finding F6.12-B: Basic assumptions about trained and qualified flight crew response to malfunctions used in the design and certification of the B737-8 MAX did not appear to hold in the two accident cases, based on preliminary information.	In-scope

ID	Recommendation	In-scope/ Out-of-scope
7-89	Recommendation R7.1: The FAA should expand its aircraft certification resources in human factors and in human system integration to enable the thorough analysis and verification of compliance with such regulatory requirements as 14 CFR §§ 25.1302 (Installed Systems and Equipment for Use by the Flightcrew) and 25.1322 (Flightcrew Alerting).	Out-of-scope (specific for Boeing)
7-91	Recommendation R8.2: The FAA, as part of the BASOO oversight activities, should review the Boeing safety analysis process, including how candidate items are identified for the S&MF analysis, to ensure hazards are assessed in an integrated manner across systems and subsystems, and all credible hazards are identified for assessment at the aircraft level.	Out-of-scope (specific for Boeing)
7-92	Recommendation R8.3: The FAA, as part of the BASOO oversight activities, should review the Boeing safety analysis process and ensure it is aligned with the Boeing development assurance process to meet the objectives of ARP4754A. A more robust alignment between these two processes will ensure completeness of hazard identification in the S&MF candidate list, identification of all critical failure modes, and incorporation of the mitigations into the design.	Out-of-scope (specific for Boeing)
7-93	Recommendation R8.4: The FAA, as part of the BASOO oversight activities, should review the Boeing process for managing assumptions to ensure assumptions are visible throughout the development assurance and safety analysis processes. Increased visibility includes the integrated reassessment of assumptions to ensure that associated hazards are appropriately identified and remain valid and that the design complies with functional and safety requirements derived from assumptions.	Out-of-scope (specific to Boeing)
7-94	Recommendation R8.5: The FAA, as part of the BASOO oversight activities, should ensure Boeing implements a more iterative approach to verify and validate requirement functional dependencies and assess the interaction between hazards identified at the system level and the aircraft level. Such an approach would increase the involvement of system safety specialists, human factors specialists, and pilots to perform independent reviews of potential hazard impacts at the aircraft level. This independent review would supplement and inform the aircraft-level development assurance integration activities carried out by the Boeing chief pilot/test pilot.	Out-of-scope (specific to Boeing)

ID	Recommendation	In-scope/ Out-of-scope
7-96	Recommendation R8.10: The FAA should review AC 20-174 to ensure that expectations for a holistic aircraft-level design assurance practice for transport category aircraft is achieved which includes consideration of all systems (including safety) requirements and assumptions. In particular, the AC should address how credit can be given for traditional techniques for simple deterministic systems within a structured methodology.	Out-of-scope (internal to regulators)
7-97	Recommendation R8.12: The FAA should ensure that agreement of any limited application of a development assurance process includes the requirement for the applicant's safety analysis processes to satisfy the ARP 4754A safety assessment objectives. o Observation O8.12-A: The limited application of a development assurance process agreed between the FAA and Boeing did not adequately consider the applicant's safety analysis process and how that integrates with the tailored development assurance process for complex and integrated systems. a) The FAA's participation in system reviews did not result in ensuring Boeing's process was equivalent to ARP4754A. b) The expectation that safety requirements be considered within the design assurance process was not realized. c) ARP4754A Section 6 provides the necessary guidance for modifications to aircraft or systems. d) ARP4754A Section 5.1 details the objectives of the safety assessment process regarding analysis of functional interactions and interdependencies.	Out-of-scope (internal to regulators)
7-98	Recommendation R9.5: The FAA should conduct a study to determine the value of AEG pilots receiving familiarization training to enhance their understanding of certification flight tests.	Out-of-scope (internal to regulators)
7-99	Recommendation R10 Based on the JATR team's findings and observations related to flight crew training, JATR team members recommend that the FAA require a documented process to determine what information will be included in the Airplane Flight Manual, the Flight Crew Operating Manual, and the Flight Crew Training Manual. The FAA should review training programs to ensure flight crews are competent in the handling of mis-trim events.	Out-of-scope (specific for Boeing)
7-100	Recommendation R10.1: The FAA should include in the FSB report the flight experience level and qualification of the flight crew used to assess the effectiveness of the differences training.	Out-of-scope (internal to regulators)
7-101	Recommendation R10.2: The FAA should review the B737 MAX type rating training program to include training in the operation of the manual stabilizer trim wheel throughout the speed range.	Out-of-scope (specific for Boeing)

ID	Recommendation	In-scope/ Out-of-scope
7-102	Recommendation R10.3: The FAA should require operators of the B737 to include operation of the manual stabilizer trim wheel throughout the speed range in their recurrent training programs.	Out-of-scope (specific for Boeing)
7-103	Recommendation R10.4: The FAA should add a special emphasis training item to the B737 FSB Report to include training in the operation of the main electric stabilizer trim and the manual stabilizer trim wheel and recovery from a mis-trim state throughout the speed range.	Out-of-scope (specific for Boeing)
7-106	Recommendation R12 JATR team members recommend that the FAA review its policies for analyzing safety risk and implementing interim airworthiness directive action following a fatal transport aircraft accident. The FAA should ensure that it shares post-accident safety information with the international community to the maximum extent possible.	Out-of-scope (internal to regulators)
7-107	Recommendation R12.1: The FAA should review FAA Order 8110.107A, Monitor Safety/Analyze Data, and consider reducing the control program risk guideline for post-accident corrective action if a catastrophic fatal accident of a transport category aircraft has occurred. For example, the allowable FAA Monitor Safety/Analyze Data (MSAD) guidelines for control program fleet risk for the related corrective action could be reduced to between 10% and 25% of their normal values.	Out-of-scope (internal to regulators)
7-108	Recommendation R12.2: The FAA, in harmonization with other CAAs, should review the airworthiness directive processes to determine the need and proper intervals for a flight crew pre-flight briefing when an interim action AD mandates an existing AFM procedure or mandates a revision to the AFM to address a major contributing factor to a catastrophic fatal accident of a transport category aircraft.	Out-of-scope (internal to regulators)
7-109	Recommendation R12.3: Where the FAA assigns responsibility for continued operational safety oversight of a product to a different FAA office than the one that conducted oversight of the type certification, the agency should ensure that it has sufficient mechanisms in place for the transfer of requisite technical knowledge about the design to the responsible office.	Out-of-scope (internal to regulators)
7-110	Recommendation R12.4: The FAA should review its safety information sharing policy to ensure that it shares technical safety information with other CAAs to the maximum extent possible. Maximum sharing of such information would enhance safety and minimize incorrect speculation by parties that are not participants in an ongoing accident investigation.	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
8-1	Refer to the CASR Part 91.7 Civil Aircraft Airworthiness and the Operation Manual part A subchapter 1.4.2, the pilot in command shall discontinue the flight when un-airworthy mechanical, electrical, or structural conditions occur. The flight from Denpasar to Jakarta experienced stick shaker activation during the takeoff rotation and remained active throughout the flight. This condition is considered as un-airworthy condition and the flight shall not be continued. KNKT recommend ensuring the implementation of the Operation Manual part A subchapter 1.4.2 in order to improve the safety culture and to enable the pilot to make proper decision to continue the flight.	Out-of-scope (internal to regulators)
9-1	Require that for all other US type-certificated transport-category airplanes, manufacturers (1) ensure that system safety assessments for which they assumed immediate and appropriate pilot corrective actions in response to uncommanded flight control inputs consider the effect of all possible flight deck alerts and indications on pilot recognition and response; (A-19-11)	In-scope
9-2	Require that for all other US type-certificated transport-category airplanes, manufacturers (2) incorporate design enhancements (including flight deck alerts and indications), pilot procedures, and/or training requirements, where needed, to minimize the potential for and safety impact of pilot actions that are inconsistent with manufacturer assumptions. (A-19-11)	In-scope
9-3	Develop robust tools and methods, with the input of industry and human factors experts, for use in validating assumptions about pilot recognition and response to safety-significant failure conditions as part of the design certification process. (A-19-13)	In-scope
9-4	Once the tools and methods have been developed as recommended in Recommendation A-19-13, revise existing Federal Aviation Administration (FAA) regulations and guidance to incorporate their use and documentation as part of the design certification process, including re-examining the validity of pilot recognition and response assumptions permitted in existing FAA guidance. (A-19-14)	In-scope
9-5	Develop design standards, with the input of industry and human factors experts, for aircraft system diagnostic tools that improve the prioritization and clarity of failure indications (direct and indirect) presented to pilots to improve the timeliness and effectiveness of their response. (A-19-15)	In-scope

ID	Recommendation	In-scope/ Out-of-scope
9-6	Once the design standards have been developed as recommended in Recommendation A-19-15, require implementation of system diagnostic tools on transport-category aircraft to improve the timeliness and effectiveness of pilots' response when multiple flight deck alerts and indications are present. (A-19-16)	In-scope
9-7	Notify other international regulators that certify transport-category airplane type designs (for example, the European Union Aviation Safety Agency, Transport Canada, the National Civil Aviation Agency-Brazil, the Civil Aviation Administration of China, and the Russian Federal Air Transport Agency) of Recommendation A-19-11 and encourage them to evaluate its relevance to their processes and address any changes, if applicable. (A-19-12)	Out-of-scope (internal to regulators)
10-1	(Not from doc) Provide Human Factors training for ASIs to be able to validate any assumptions that are made by the applicant in the safety analyses.	Out-of-scope (internal to regulators)
10-2	(Not from doc) Provide Human Factors training for ASIs to be able to identify and validate mental models of pilots for new elements of a system.	Out-of-scope (internal to regulators)
11-1	In November 2012, for instance, it took a Boeing test pilot more than 10 seconds to respond to uncommanded MCAS activation during a flight simulator test, a condition the pilot found to be "catastrophic[.]"128 The FAA has provided guidance that pilots should be able to respond to this condition within four seconds.129 This event should have focused Boeing's attention on the need for enhanced pilot training for MAX pilots. It didn't.	Out-of-scope (specific for Boeing)
11-2	On February 6, 2014, the FAA cited one issue -related to this topic. "Within the Boeing proposed exceptions, there may be differences of opinion between the FAA and Boeing with regards to the supporting rationale," the FAA declared.267 "For example, Boeing stated that a major reason for not stepping up to the latest amendment is to minimize the impact of changes in the flight deck and maintain a common flight deck philosophy with the 737 fleet of airplanes. Boeing also asserted that updating the 737-8 with an engine-indicating and crew alerting system [EICAS] type system will have a major impact on the type rating and training difference level between the 737-8 and the rest of the 737NG family."268	Out-of-scope (specific for Boeing)

ID	Recommendation	In-scope/ Out-of-scope
11-3	Boeing obtained an FAA exception to allow the company to not install an Engine Indicating and Crew Alerting System (EICAS) on the 737 MAX.269 Since 1982, an EICAS or its equivalent among Airbus airplanes has been common in newly certificated transport aircraft. It displays aircraft system faults and failures in the cockpit and helps pilots prioritize responding to multiple or simultaneous indications and alerts, which are often accompanied by aural alerts specific to the level of severity of a particular fault.270 But the exception from FAA relieved Boeing of the requirement that the 737 MAX must be equipped with a caution, alert, and advisory system that "[p]rovide[s] timely attention-getting cues through at least two different senses by a combination of aural, visual, or tactile indications" and that "[p]revent[s] the presentation of an alert that is inappropriate or unnecessary."271 Instead, the 737 MAX largely uses legacy cautions, warnings, alerts, and advisories from the previous generation of the 737 aircraft.272	Out-of-scope (specific for Boeing)
11-4	The National Transportation Safety Board (NTSB) emphasized the need for warning systems like EICAS in a report it issued in response to the Lion Air and Ethiopian Airlines crashes in September 2019, writing: Multiple alerts and indications in the cockpit can increase pilots' workload and can also make it more difficult to identify which procedure the pilots should conduct. Human factors research has identified that, for non-normal conditions, such as those involving a system failure with multiple alerts, where there may be multiple flight crew actions required, providing pilots with understanding as to which actions must take priority is a critical need.287	Out-of-scope (specific for Boeing)

ID	Recommendation	In-scope/ Out-of-scope
11-5	In addition, the NTSB has also pointed out that critical human factors considerations were lacking during the certification of the 737 MAX but did not specifically distinguish between the different types of certification processes.288 According to its September 2019 report: The NTSB notes that a number of human performance research studies have been conducted in the years since the certification guidance contained in AC 25.1309-1A was put in place (in 1988) [I]t is likely that more rigorous, validated methodologies exist today to assess error tolerance with regard to pilot recognition and response to failure conditions. The NTSB also believes that the use of validated methods and tools to assess pilot performance in dealing with failure conditions and emergencies would result in more effective requirements for flight deck interface design, pilot procedures, and training strategies. However, we are concerned that such tools and methods are still not commonplace or required as part of the design certification process	In-scope
11-7	While certification guidance does not incorporate the more rigorous methodologies that have been developed since FAA Advisory Circular 25.1309-1A on “System Design and Analysis” was issued in 1988, it is reasonable to think that certifying the 737 MAX as a new aircraft, rather than a 737-derivative model, under the ATC process, may have helped to identify the potential safety implications of new technologies that were incorporated into the 737 MAX. This would have allowed for a more holistic assessment of all of the functions of all of the plane’s systems.	Out-of-scope (specific for Boeing)

ID	Recommendation	In-scope/ Out-of-scope
11-8	In contrast, certifying the 737 MAX as a derivative model led Boeing's engineers and managers to think about how to minimize the impact of new features, such as MCAS, on older, established technologies that had already been certified on previous 737 aircraft. As a result, designers thought narrowly about MCAS as a discrete addition. This also limited their evaluation of how MCAS would function along with, or at the same time as, other, seemingly unrelated systems. Efforts to access the potential cascading effects MCAS could have on these other systems and on the pilots' ability to control the aircraft as a result of an MCAS malfunction or design flaw were not evaluated thoroughly enough.301 Not adequately assessing the unintended consequences of new technologies, or new functions or applications of existing technologies, on older components of the 737 MAX led to missed opportunities to identify potential safety risks to the aircraft, passengers, and crew.	Out-of-scope (specific for Boeing)
11-9	Both Boeing and the FAA758 have argued that an AOA Disagree alert is not a safety critical feature. Boeing has also said that the AOA Disagree alert only "provides the flight crew with supplemental information, not necessary for safety of flight. The alert may direct the crew to primary flight indicators, such as the airspeed and altitude alerts, which direct specific pilot action. The alert itself, however, has never been designed to prompt any specific action by the crew…"759	Out-of-scope (specific for Boeing)
11-10	Nevertheless, as Boeing has also acknowledged to the Committee, the AOA Disagree alert "would help in understanding flight deck effects resulting from the undetected failure of an AOA sensor."760 Both MAX crashes involved faulty AOA input data from the aircraft's AOA sensors.761	Out-of-scope (specific for Boeing)
11-11	More broadly, in his prepared testimony for the Committee's December 2019, hearing, FAA Administrator Dickson acknowledged several issues the FAA needs to address to improve its certification process, including: • moving toward a more holistic versus transactional, item-by-item approach to aircraft certification—taking into account the interactions between all aircraft systems and the crew;	Out-of-scope (internal to regulators)
11-11	More broadly, in his prepared testimony for the Committee's December 2019, hearing, FAA Administrator Dickson acknowledged several issues the FAA needs to address to improve its certification process, including: • integrating human factors considerations more effectively throughout the design process, as aircraft become more automated and systems more complex; and	Out-of-scope (internal to regulators)

ID	Recommendation	In-scope/ Out-of-scope
11-11	More broadly, in his prepared testimony for the Committee's December 2019, hearing, FAA Administrator Dickson acknowledged several issues the FAA needs to address to improve its certification process, including: • ensuring coordinated and flexible information flow during the oversight process.1354	Out-of-scope (internal to regulators)
11-14	NTSB recommendation: The NTSB also believes that the use of validated methods and tools to assess pilot performance in dealing with failure conditions and emergencies would result in more effective requirements for flight deck interface design, pilot procedures, and training strategies. However, we are concerned that such tools and methods are still not commonplace or required as part of the design certification process for functions such as MCAS on newly certified type designs.	Out-of-scope (specific for Boeing)
11-17	To the FAA: Integrating human factors considerations more effectively throughout the design process, as aircraft become more automated and systems more complex;	Out-of-scope (internal to regulators)
12-1	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.	Out-of-scope (specific for Boeing)
12-3	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.	Out-of-scope (specific for Boeing)
12-4	Add the notes from the QRH Stab Trim Inop procedure to the Runaway Stabilizer procedure.	Out-of-scope (specific for Boeing)
12-5	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.	Out-of-scope (specific for Boeing)
12-6	Boeing to add step (if necessary) autothrottle disengage in Stabilizer Trim Inoperative checklist in QRH.	Out-of-scope (specific for Boeing)
12-7	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.	Out-of-scope (internal to regulators)
12-8	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.	Out-of-scope (specific to Boeing)

Appendix C. Consolidated List of GAMA FDHFWG Recommendations

Sect.	#	GAMA Recommendation Description
4.1	1	Industry should create a methodology for the validation, documentation, and traceability of assumptions for flightcrew behavior and response (e.g., actions), including the effect(s) of failure conditions.
4.2	2	Industry should develop a methodology for the demonstration of realistic pilot response time for failure conditions. The pilot response time should account for both pilot recognition and reaction.
4.3	3	Industry should develop a methodology to define the role of the different types of pilots (e.g., flight test pilots, production test pilots, and certification authority pilots) and to identify what an appropriate representation of a qualified flightcrew should be for scenario-based human factors evaluations and tests.
4.4	4	Industry should create a formal training course for Human Factors practitioners on how to incorporate Human Factors into the overall system development and aircraft certification process.
4.5	5	Industry should create tools and methods for Human Factors considerations in Functional Hazard Assessments.
	6	Industry should create a methodology on how to implement a closed feedback loop between relevant in-service data, Human Factors evaluations/tests, and the design and Functional Hazard Assessments.
4.6	7	Industry should create a methodology on how to perform a Flight Crew Human Error Analysis.
4.7	8	EASA should consider expanding AMC 25.671 Control Systems and the FAA should harmonize with AMC 25.671 so that the applicant obtains early concurrence of the certification authority on the choice of an acceptable means of compliance.
4.8	9	The FAA should review the Changed Product Rule and consider expanding the guidance to cover the impact of changes to the roles and responsibilities of the flightcrew, procedures for the safe operation of the aircraft, and qualifications and training of the flightcrew, especially when making a determination of a “substantial change”.
4.9	10	The FAA should consider including additional guidance in AC 25.1302-1 for changes to a design in cases where the changed product process will be used and harmonize with EASA AMC 25.1302. In addition, AC/AMC 25.1302 could be expanded to include how the assessment of novelty, complexity, and integration apply within the changed product rule.
	11	The FAA should consider expanding AC 25.1302-1 to provide further guidance on how both single and multiple failures are assessed, and any provisions necessary for adequate HMI following the failure(s).
	12	Certification applicants should perform a review of system design changes that rely on original aircraft- and system- level assumptions that they are relying on to ensure they are not inconsistent with those assumptions. In addition, industry should develop a methodology (e.g., a checklist with a decision tree) to determine the impact of discrete changes at the aircraft and

Sect.	#	GAMA Recommendation Description
		system level to ensure that new changes are not inconsistent with the original design assumptions
4.10	13	The FAA and EASA should consider harmonizing guidance materials AC 25.1329-1C, AMC 25.1329, AC 25-7D and AMC 25.255.
	14	The FAA should consider harmonizing AC 25.1309-1 with EASA AMC 25.1309 Amdt. 27.
4.11	15	The FAA should consider updated AC 25.1581-1 to include criteria used to determine the content to be included in the AFM, FCOM, and FCTM and identify the relevant stakeholders that should be included within the review on the content included.

Appendix D. Contributors

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Appendix E. List of Abbreviations and Acronyms

AC	Advisory Circular
ACSAA	Aircraft Certification, Safety and Accountability Act
AEG	Aircraft Evaluation Group
AFM	Airplane Flight Manual
AIA	Aerospace Industries Association
AMC	Acceptable Means of Compliance
Amdt.	Amendment
AOA	Angle of Attack
CATA	Certification Authorities for Transport Airplanes
CDO	Certified Design Organization
CFR	Code of Federal Regulations
CS	Certification Specification
EASA	European Union Aviation Safety Agency
EICAS	Engine Indicating and Crew Alerting System
FAA	Federal Aviation Administration
FCOM	Flight Crew Operational Manual
FCTM	Flight Crew Training Manual
FDHFWG	Flight Deck Human Factors Working Group
FFS	Full Flight Simulator
FHA	Functional Hazard Assessments
HF	Human Factors
HFE	Human Factors Engineering
GAMA	General Aviation Manufacturers Association
HEA	Human Error Analysis
ID	Identification
JATR	Joint Authorities Technical Review
MCAS	Maneuvering Characteristics Augmentation System
NPA	Notice for Proposed Amendment
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturers
OSD	Operational Suitability Data
PSP	Partnership for Safety Plan
SSA	System Safety Assessments
STC	Supplemental Type Certificate
TAB	Technical Advisory Board
TC	Type Certificate
TCDS	Type Certificate Data Sheet
US	United States