December 16, 2024
GAMA Publication #22

General Aviation Manufacturers Association

Predictive Flightcrew Human Error Analysis

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

In 2023 the General Aviation Manufacturers Association (GAMA) Flight Deck Human Factors Working Group (FDHFWG) completed an analysis of human factors recommendations that stemmed from multiple Boeing 737 MAX accidents related publications. A key GAMA recommendation from that work was that “industry should create a methodology on how to perform a flightcrew Human Error Analysis.”

This is a GAMA document that describes the generic components of a predictive flightcrew Human Error Analysis (HEA) process / methodology. It is not intended to be a prescriptive method but rather a resource for consideration. GAMA recognizes that organizations may have an HEA methodology, for which this document could provide supplemental information.

The predictive HEA components are as follows:

- Identify the flightcrew error – this methodology utilizes a qualitative method to identify flightcrew errors;
- Describe the flightcrew error without mitigations and determine the severity;
- Identify mitigations; and
- Describe the flightcrew error with mitigations and determine the severity.

The predictive HEA can be utilized for both development and certification.

1 Introduction

In 2023 the General Aviation Manufacturers Association (GAMA) Flight Deck Human Factors Working Group (FDHFWG) completed an analysis of human factors recommendations that stemmed from multiple Boeing 737 MAX accidents related publications (GAMA, 2023). A key GAMA recommendation from that work was that “industry should create a methodology on how to perform a flightcrew Human Error Analysis.”

This is a GAMA document that describes the generic components of a predictive flightcrew Human Error Analysis (HEA) process / methodology. It is not intended to be a prescriptive method but rather a resource for consideration. GAMA recognizes that organizations may have an HEA methodology, for which this document could provide supplemental information.

The method described in this document is for a predictive HEA (and does not include analysis of an observed flightcrew error in an evaluation or test). For the purpose of this document, the term HEA will be used and denotes a predictive HEA.

The methodology provided herein references FAA 14 CFR Part 25 (EASA CS-25) aircraft; however, consideration should be given to the practical and appropriate application across Part (CS) 23, 27, and 29 aircraft (as well as aircraft that may not fit specifically in these parts, e.g., Powered-Lift).

An HEA is a systematic approach to determine if a flightcrew error effect is acceptable. Aspects include identifying potential flightcrew errors, determining the effect of the flightcrew error without mitigations, identifying mitigations, and determining the effect of the flightcrew error with mitigations. This document utilizes a qualitative method to identify flightcrew errors.

The purpose of an HEA is to be used as part of the design process to mitigate development risks and to support the demonstration of compliance substantiation for flightcrew error-related regulations. The applicant can determine which aspects to utilize for development and certification (e.g., there may be more content in the development document, and less / summarized content for the certification document).

Throughout this document, the creator of the HEA will be referred to as “the applicant”. While this terminology is usually specific to the certification environment, the intent is to make this methodology generalizable to both development and certification HEAs. Therefore, consider the term “the applicant” applicable to HEA creation within and outside of certification efforts.

The scope of the HEA methodology described in this document, specifically when the HEA is used for certification, is limited to potential errors of commission and omission by a qualified flightcrew in the flight deck while operating the airplane in both normal and non-normal conditions (as specified in AC/AMC 25.1302). This is discussed in more detail in Section 3.1. Other flightcrew tasks (e.g., pre-flight walkaround the aircraft) can be considered for development purposes but are not within scope of 14 CFR / CS 25.1302 compliance.

Both the development and certification processes can benefit from an HEA. The development process can benefit from performing an HEA early, since it provides a means to identify potential flightcrew errors and provides mitigations as part of the design solution. In addition, it may support the ongoing validation of design solutions, procedures, and training.

Within the certification process, an HEA can serve as an analysis means of compliance for flightcrew error-related regulations, especially for safety-critical items where certification authorities require extra scrutiny, and can be done before means of compliance by test is possible. The HEA may be utilized either alone or in combination with other means of compliance – this will depend on the program specifics.

The HEA methodology uses a similar approach and terminology as is done for Functional Hazard Assessments (FHAs) (e.g., severity classifications). However, a flightcrew error is not the same as a failure condition. This is described within this document.

In this document, the terms flightcrew perception, decision-making, and response are used. The use of these information processing terms can vary in industry and guidance documents and need to be agreed to with the certification authority.

1.1 Task Description and Objectives

The creation of this document was based on recommendation #7 in GAMA Publication #21 Boeing 737 MAX Related Reports & Recommendations and their Impact on Human Factors (GAMA, 2023), developed by the GAMA Flight Deck Human Factors Working Group (FDHFWG). This recommendation states, “Industry should create a methodology on how to perform a flightcrew Human Error Analysis”, and provides additional background:

> “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.”

1.2 Regulation Considerations

An HEA can be used to support compliance to the regulations below. When referencing FAA and EASA regulations and guidance material in this document, the applicant should consider those relevant to their certification authority.

Regulations stated below, and their associated amendment levels, are applicable at the time of this document’s release. The applicant should review the applicable regulations at the time of utilizing this document.

Table 1 – Applicable Regulations

Regulation	Title
FAA	
25.1302(a)(b)(c)(d)	Installed systems and equipment for use by the flightcrew.
25.1309(c)	Equipment, systems, and installations.
25.1329(i)	Flight guidance system.
EASA	
25.1302(a)(b)(c)(d)	Installed systems and equipment for use by the flight crew.
25.1309(c)	Equipment, systems and installations.
25.1329(i)	Flight Guidance System.
Transport Canada	
525.1302(a)(b)(c)(d)	Installed Systems and Equipment for Use by Flight Crew Members.
525.1309(c)	Equipment, Systems, and Installations.
525.1329(i)	Flight Guidance System.
ANAC	
25.1302(a)(b)(c)(d)	Installed systems and equipment for use by the flightcrew.
25.1309(c)	Equipment, systems, and installations.
25.1329(i)	Flight guidance system.

The HEA can provide a more comprehensive assessment of possible flightcrew errors as compared to evaluations and tests, when showing compliance to the applicable regulations. During evaluations and tests, flightcrew errors may not be observed due to their limited frequency of occurrence. In addition, to intentionally assess a flightcrew error in an evaluation and test may require priming the participant in a way which may impact the overall outcome of the evaluation / test.

However, after conducting an HEA there may still be a need for a simulator test and / or flight test as an additional means to support demonstration of compliance with multiple pilot evaluators to confirm if all potential flightcrew errors have been addressed by the HEA. These tests are typically to support the demonstration of compliance to several regulations, not only those related to flightcrew error.

It is important to note that applicants' needs will vary with respect to the scope and timing of an HEA. As it pertains to a certification deliverable, the timing depends on the type of certification program it is intended for such as original Type Certificate (TC), Amended Type Certificate (ATC), or a Supplemental Type Certificate (STC), and if flightcrew error related regulations are part of the certification basis. The scope and detail of the HEA content should be presented and agreed upon with the responsible certification authority. Agreement on this approach early in a certification program will facilitate alignment with the certification authority on the applicant's intent on utilizing an HEA to support demonstration of compliance.

2 Inputs to an HEA

2.1 HEA Applicability, Prerequisites to Perform an HEA, and When to Perform an HEA

HEA Applicability

The applicant should determine early in a program if an HEA is applicable. To determine this, the applicant should consider the design items (defined per AMC 25.1302 Amendment 28), overall flight deck design, and scope and certification basis of the program. For example:

- For new aircraft models, with an entirely new flight deck, an HEA may be applicable and should be started early in the development process.
- For new aircraft models or derivative aircraft, with a previously certified flight deck, the applicant should determine whether similarity can be utilized in lieu of an HEA. However, if there is a modification in flightcrew interaction with the flight deck, whether a modification in task allocation, an interface change, new or modified procedures, an HEA may be applicable and should be started early in the development process.
- For any aircraft model, whenever there is a modification in flightcrew interaction with the flight deck, whether a modification in task allocation, an interface change, new or modified procedures, an HEA may be applicable. An HEA should be updated or created for the differences and should be started early in the development process.

Prerequisites to Perform an HEA

The HEA team should be defined when starting an HEA, including personnel with knowledge of human factors, flight operations (pilots), system design, and system safety (see Section 2.2). To begin the HEA, various data will be needed such as the description of the design item(s) under analysis and a description of the flight deck effects when the flightcrew error occurs (see Section 2.3). In addition, a task analysis is needed to perform an HEA (see Section 3.2).

A supplier may provide content (e.g., a supplier HEA) for the applicant (such as aircraft manufacturer) to consider.

When to Perform an HEA

The HEA should be conducted throughout the development, but when performed early in the design process to inform preliminary design requirements, it can better inform the user interface design and identification of effective mitigations to reduce the severity of flightcrew errors. The timing of HEA activities will be program-dependent based on design maturity. The HEA can be formalized to support certification when the design is sufficiently mature and functions well understood. An HEA started late in the design process would make it more difficult to implement design modifications driven by the HEA.

Submitting the HEA for compliance is recommended when all relevant design items have been analyzed, and there are no planned modifications to the design items that would invalidate the analyses. The sequence of an HEA submission to the certification authority should be considered and included in the certification plan.

2.2 Define Personnel to Prepare and Review the HEA

2.2.1 Purpose

The appropriate personnel should be involved in preparing and reviewing the HEA to ensure it is developed using an acceptable methodology and the content is correct and complete. The HEA team personnel knowledge should include human factors, flight operations (pilots), system design, and system safety, as relevant to the aspects under consideration in the HEA (e.g., the entire flight deck or system(s)). These personnel contribute to the HEA in different ways, as described below.

2.2.2 Considerations

The HEA team should have a depth of knowledge in human factors, flight operations (pilots), system design, and system safety. The minimum personnel composition is such that all of these knowledge areas are covered. It is strongly recommended that the personnel composition includes a unique person(s) for each knowledge area, which results in different sets of expertise and views to help ensure a more correct and complete HEA (although it is recognized that this will vary across organizations). The HEA team should have knowledge of the HEA method and how they contribute to it, knowledge of the relevant regulatory material, and knowledge of the aircraft, flight deck, and system(s) that are the subject of the HEA to perform their responsibilities.

Human Factors

The person(s) representing Human Factors should be responsible for being the primary author for the HEA. This includes establishing the HEA method by either following an existing method, scoping the method to the specific HEA, or developing a new HEA method.

Pilots

The person(s) representing pilots should be responsible for supporting aspects of the HEA, such as task analysis, flightcrew response to the flightcrew error, and severity of flightcrew error, and should work closely with Human Factors. Ultimately, operational experience is critical for accurate support to task analysis and flightcrew error scenarios and determination. It may be helpful that the person(s) has a variety of backgrounds as a test pilot, line pilot, etc., for different perspectives such as for task analysis and flightcrew error severity ratings.

The criteria for the number of pilots involved in the HEA should be established and documented by the applicant.

System Design (Avionics, Mechanical, etc.)

The person(s) representing System Design (preferably at least one specialist from each applicable system and subsystem) should be responsible for supporting aspects of the HEA, such as the accuracy of system content (e.g., system descriptions, system functionality, and design).

System Safety

The person(s) representing System Safety should be responsible for supporting aspects of the HEA related to a flightcrew error occurring when responding to a failure condition. Ideally, this is the person responsible for the FHA that includes the failure condition.

2.3 Describe the Aircraft, Operation, Flight Deck, and Systems

2.3.1 Purpose

The purpose of this section is to describe the content related to the aircraft, operations, flight deck, and systems included within the HEA. It is acceptable for the HEA to reference documents that contain that content (e.g., concept of operations, flight deck philosophy, certification plan, system description document), or include them within the HEA. The choice will vary by company, type of program, and stage of development.

2.3.2 Considerations

The HEA itself, or those documents referenced within the HEA, should provide sufficient background information at the correct level of definition to support the analysis. Too little information can make the aircraft and system behavior difficult to understand and may not provide sufficient detail to complete the analysis. Too much information can make it challenging to understand the information that is actually relevant to the analysis.

The breadth and depth of content in the HEA will evolve throughout the aircraft design process. Early in the process, there is less definition of the aircraft design and thus less definition in the HEA. As the aircraft design matures, there is more known about the aircraft operations, the systems and equipment, and the flightcrew interaction with the aircraft. The HEA team will need to monitor the design progression to ensure the HEA reflects the current design.

Aircraft and Operation

The HEA should include a general description of the aircraft and operation, and may include but not be limited to the content below. Note that some of the information below are general details only for the reader of the HEA (e.g., certification authority) and may not affect the HEA.

- Certification regulations (e.g., Part 23, 25, 27, 29).
- Operational regulations (e.g., Part 91, 121, 135, EU Air Ops CAT).
- Aircraft mission (e.g., passenger transport, sightseeing, or cargo).
- Minimum and maximum flightcrew (e.g., certified single pilot but can have two pilots).
- Number of passengers.
- Maximum altitude.
- Maximum cruise speed.
- Meteorological conditions (e.g., visibility, specific weather conditions).
- Types of operation (e.g., VFR, IFR, CAT I, II, III, RNP).

Flight Deck and System(s)

The HEA should include a description of the flight deck and systems relevant to the subject of the HEA, and may include:

- Intended function of the design item.
- Flight deck layout, images / drawings, and general description (identifying the equipment and general component location). This could also include videos.
- Location of pilot(s) (e.g., Design Eye Position in relation to the surrounding flight deck).

- Number, size, and location of displays.
- System layout, operation, and behavior (such as what is in a System Description Document).
    - This would include, for example, description of flightcrew interaction with the system, such as control input methods (line select key, cursor control device, touch screen, voice, etc.), and display windows management.
- Windshield and side window layout, especially if there are any limitations or exceedances compared to similar aircraft.
- Vision systems such as Synthetic Vision System, Enhanced Vision System, electro-optical, Combined Vision System, etc.
- Alerting systems.
- New / novel systems / equipment.
- Content from the Aircraft Flight Manual (AFM), Quick Reference Handbook (QRH), etc.

3 HEA Methodology

The HEA methodology overview is shown in Figure 1 and described below. The output of the HEA could be captured in an HEA Worksheet – an example is shown in Appendix C.

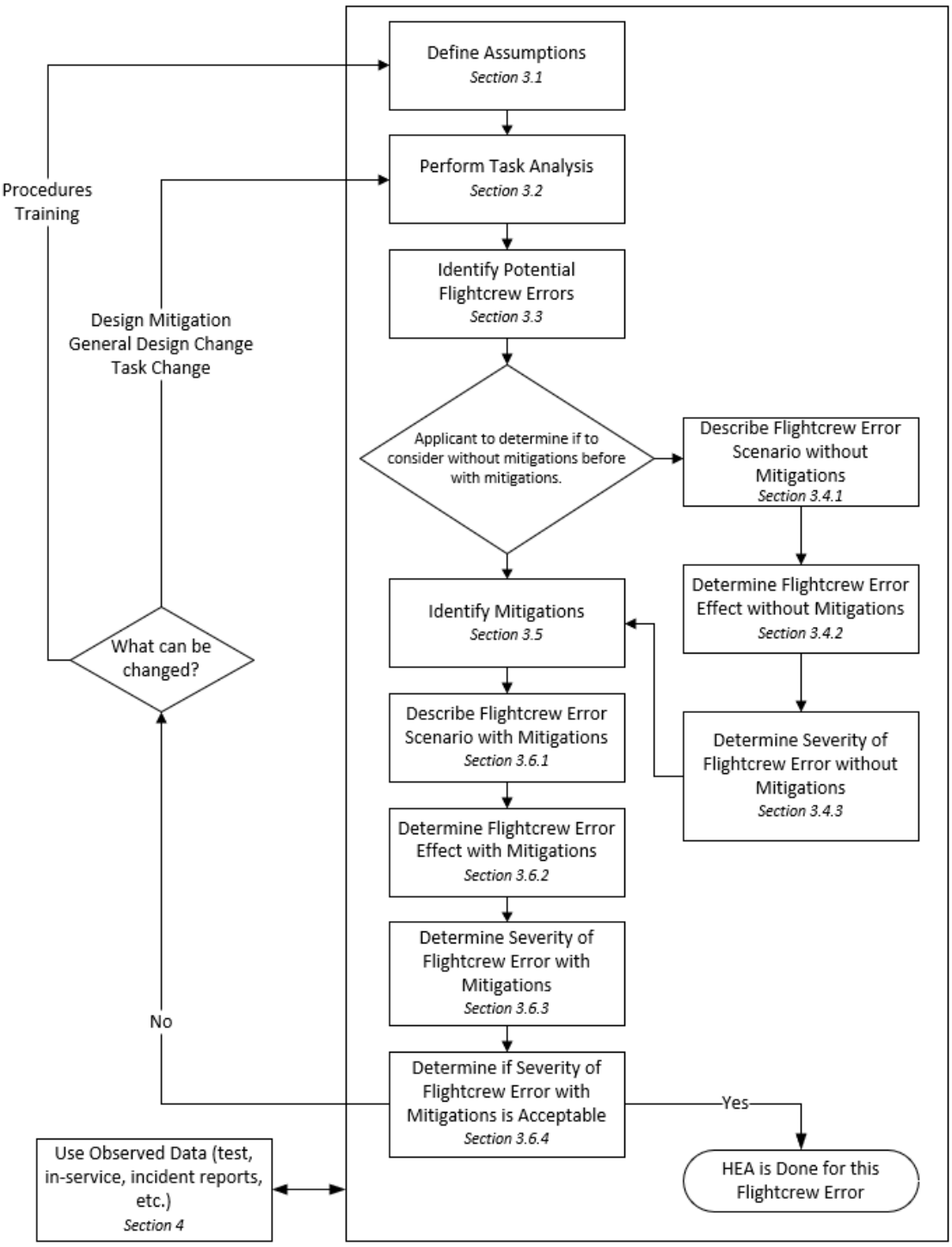

Figure 1 – Overview of HEA Methodology Process

An HEA can be structured similarly to an FHA; however, a flightcrew error is not considered a failure of the flightcrew. The HEA starts with a flightcrew error, assesses the flightcrew ability to manage the flightcrew error, and determines the severity (without and with mitigations). The FHA starts with a failure condition, assesses the flightcrew ability to manage the failure condition, and determines the severity. More detail is provided below. The HEA should include the identification and documentation of human factors assumptions made regarding flightcrew perception, decision-making, and response to the flightcrew error.

Table 2 – Comparison of HEA and FHA

HEA	**FHA**
Identify design items (or entire flight deck, etc.) and their intended functions, in scope of the task analysis and HEA.	Identify functions.
Using a task analysis, identify flightcrew tasks when using the design items. When the flightcrew is performing those tasks, identify flightcrew errors per phase of flight.	Identify failure conditions per phase of flight.
Determine the Effect on Aircraft, Effect on Occupants excluding Flightcrew, and Effect on Flightcrew for each flightcrew error for each phase of flight (without and with mitigations). This document recommends using the same criteria in AC 25.1309-1B Table 4-1 and AMC 25.1309 Amendment 28 Figure 2a.	Determine the Effect on Aircraft, Effect on Occupants excluding Flightcrew, and Effect on Flightcrew for each failure condition for each phase of flight. Utilize AC 25.1309-1B Table 4-1 and AMC 25.1309 Amendment 28 Figure 2a.
Determine the severity classification for each flightcrew error for each phase of flight (without and with mitigations). This document recommends using the same criteria in AC 25.1309-1B Table 4-1 and AMC 25.1309 Amendment 28 Figure 2a.	Determine the severity classification for each failure condition for each phase of flight. Utilize AC 25.1309-1B Table 4-1 and AMC 25.1309 Amendment 28 Figure 2a.
Identify the highest severity classification for each flightcrew error considering all phases of flight (without and with mitigations).	Identify the highest severity classification for each failure condition considering all phases of flight.
The flightcrew error severity classification (with mitigations) is used to determine whether the flightcrew error is acceptable.	The failure condition severity classification and allowable probability are used to determine if the failure condition is acceptable. Utilize AC 25.1309-1B Table 4-1 and AMC 25.1309 Amendment 28 Figure 1 and 2b.

HEA	FHA
Note: For the HEA, this document does not state an inverse relationship between the probability and the severity of flightcrew error effects. AC 25.1302-1 Section 5-7.a.(7)(c) states “In most cases, the probability of flightcrew errors can’t be predicted. If an applicant chooses to use a quantitative approach, the validity of the approach should be established.” However, for certain flightcrew errors where a severity of Major or less cannot be attained using mitigations, there is an approach to using likelihood of the flightcrew error to demonstrate that the flightcrew error is no longer “reasonably expected in service” (see Section 3.7). For the flightcrew error occurring during normal conditions (per Section 3.1.2): This document recommends the acceptable severity to be Major or less because this relates to Continued Safe Flight and Landing. Reference AC 25.1302-1 Section 5-7.a.(2)(b) and AMC 25.1302 Amendment 28 Section 4.5.(a)(2)(ii). For the flightcrew error occurring when responding to a failure condition: This document does not recommend an acceptable severity classification because the failure itself is already imposing a certain severity. For example, the severity of the failure condition without flightcrew error is Hazardous; therefore, the severity of the failure condition with a flightcrew error cannot be less than Hazardous. To determine an acceptable flightcrew error when responding to a failure condition, the applicant should consider the following per 14 CFR 25.1309(c) Amdt. 25-152 (and related CS 25.1309(c) Amendment 28), “The airplane and systems must provide information concerning unsafe system operating conditions to the flightcrew to enable them to take appropriate corrective action in a timely manner. Systems	Note: AC 25.1309-1B Section 4 and AMC 25.1309 Amendment 28 Section 8 state an inverse relationship between the probability and the severity of failure condition effects.

HEA	FHA
and controls, including information, indications, and annunciations, must be designed to minimize flightcrew errors that could create additional hazards." Also reference AC 25.1309-1B Section 5.3.1.4, 5.4.1, and 8.2; AMC 25.1309 Amendment 28 Section 9.b.(1)(iv), 9.c., and 12.a.	

3.1 Define Assumptions

3.1.1 Purpose

Before starting the HEA, assumptions should be defined to bound the breadth and depth of the HEA.

3.1.2 Considerations

Aircraft and Flight Deck Design Configuration

The applicant should state the aircraft and flight deck design that is under analysis (see Section 2.3). For example, if there are avionics options for the operator to select (e.g., upgrades to purchase), then these may not be available to every operator. Therefore, the applicant may consider performing the HEA with the baseline aircraft (without those options / upgrades). This should be coordinated with the certification authority. In addition, the applicant should determine if some relevant MMEL configurations of the aircraft are to be considered in the HEA (i.e., whether the aircraft can dispatch with certain equipment inoperable).

Aircraft State

The applicant should assume a nominal aircraft state when the flightcrew enters the aircraft. There are no flightcrew or other personnel (e.g., maintenance) errors or system / equipment failures that occurred / remain from before the flightcrew enters the aircraft, unless otherwise identified.

Environmental and Operational Conditions

The applicant should assume the environmental and operational conditions that the aircraft can experience and that the system / equipment under analysis is used (see various sections of AC 25.1302-1 and AMC 25.1302 Amendment 28, including AMC 25.1302 Amendment 28 Section 4.5.(a)(4) and 4.6(d)). The applicant should determine the environmental and operational conditions that could affect flightcrew error severity. This is analogous to the environmental and operational conditions assumed in FHAs (see AC 25.1309-1B Section 1.5.17, 5.2.1, 5.2.2, 7.8; AMC 25.1309 Amendment 28 Section 5.q., 9.a.(1)(2), 11.g.; SAE ARP4761A Section A.8, C.8).

Flightcrew Errors

The HEA, when used to support demonstration of compliance, should only consider flightcrew errors as described below, per 14 CFR / CS 25.1302(d) and relevant guidance material.

14 CFR 25.1302(d) states (and a similar intent in CS 25.1302(d)):

- “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. Such installed equipment and systems must meet the following requirements:
    - (d) To the extent practicable, installed equipment must incorporate means to enable the flightcrew to manage errors resulting from the kinds of flightcrew interactions with the equipment that can be reasonably expected in service. This paragraph does not apply to any of the following:
        - (1) Skill-related errors associated with manual control of the airplane;
        - (2) Errors that result from decisions, actions, or omissions committed with malicious intent;
        - (3) Errors arising from a crewmember's reckless decisions, actions, or omissions reflecting a substantial disregard for safety; and
        - (4) Errors resulting from acts or threats of violence, including actions taken under duress.”

Regarding the text “installed systems and equipment” [in the flight deck].

- Within scope are the installed systems and equipment relevant to the applicant’s analyses, which may be all applicable systems and equipment in the flight deck (which may be appropriate for a new TC program), or specific systems and equipment in the flight deck (which may be appropriate for a Type Design Change or STC). Reference 14 CFR / CS 25.1302(d), AC 25.1302-1 Section 3-2.a and 3-2.b., AMC 25.1302 Amendment 28 Section 1.2.(b), AC 25.1302-1 Section 5-2.c.(1)(a), AMC 25.1302 Amendment 28 (GM1 25.1302 Section 2.(c)(1)(i)).

Regarding the text “flightcrew members”.

- The number of flightcrew members seated in the flight deck is the minimum flightcrew as determined for compliance to 14 CFR / CS 25.1523. Reference 14 CFR / CS 25.1302(d), AC 25.1302-1 Section 5-2.c.(1)(a), AMC 25.1302 Amendment 28 (GM1 25.1302 Section 2.(c)(1)(i)).
    - The applicant should determine if there are certain scenarios / tasks that assume more pilots operating the aircraft than the minimum flightcrew (e.g., certified for one pilot as minimum flightcrew, but can be operated by two pilots (has two pilot stations)).
    - The applicant should determine if there are certain scenarios / tasks that assume less than the minimum flightcrew is operating the aircraft (e.g., one pilot is not in the flight deck (in lavatory), one pilot is sleeping, one pilot is incapacitated).

Regarding the text “normally seated positions on the flight deck”.

- The applicant should assume that flightcrew errors within scope are those that occur when the flightcrew members are at their normally seated positions on the flight deck. Reference 14 CFR / CS 25.1302(d), AC 25.1302-1 Section 5-2.c.(1)(a), AMC 25.1302 Amendment 28 (GM1 25.1302 Section 2.(c)(1)(ii)).
    - It is recommended that this is the position established for 14 CFR / CS 25.773 (i.e., Design Eye Position); however, this is not explicit in AC 25.1302-1 or AMC 25.1302 Amendment 28.
    - It is recommended that the seat belt and shoulder harness (if provided) are fastened (per 14 CFR / CS 25.777(c)), but inertia reels are not locked.

Regarding the text “qualified flightcrew members trained in their use”.

- The applicant should assume the flightcrew is qualified and is trained in the use of the installed equipment. The flightcrew is allowed to fly the airplane because the flightcrew meets the requirements of the operating rules for transport category airplanes. Reference AC 25.1302-1 Section 3-3, AMC 25.1302 Amendment 28 (GM1 25.1302 Section 2.(c)(1)(v)), AC 25.1302-1 Section 5-2.c.(1)(c).
    - For an HEA, the intent is that the flightcrew is qualified and trained in the use of the installed equipment (the flightcrew is a future user [customer]).
    - For evaluations and tests, the flightcrew should be adequately trained in the use of the installed equipment such that flightcrew errors attributed to lack of training are minimized (i.e., training per AMC 25.1302 Amendment 28 Section 3.3.2.(h)).
- The applicant should assume the flightcrew meets minimum crew rest requirements as required by regulatory requirements. This is implied per the “qualified flightcrew” statement.
- The applicant should assume the flightcrew meets minimum medical requirements as required by regulatory requirements. This is implied per the “qualified flightcrew” statement.
- The applicant should assume the flightcrew make errors even if well trained, qualified, healthy, rested, and alert. Reference AC 25.1302-1 Section 2-1.b., AMC 25.1302 Amendment 28 (GM1 25.1302 Section 1.(b)), AC 25.1302-1 Section 5-7.a.(1), AMC 25.1302 Amendment 28 Section 4.5.(a)(1), AC 25.1302-1 Section 5-2.c.(10), AMC 25.1302 Amendment 28 (GM1 25.1302 Section 2.(c)(10)).

Regarding the text “safely perform all of the tasks associated with the systems' and equipment's intended functions”.

- The applicant should include flightcrew tasks when operating the airplane in normal and non-normal conditions. The applicant should determine the specific scenarios and conditions to consider in the HEA. Reference AC 25.1302-1 Section 3-2.a. and 3-2.b., AMC 25.1302 Amendment 28 Section 1.2.(b), AMC 25.1302 Amendment 28 (GM1 25.1302 Section 2.(c)(1)(ii)), AC 25.1309-1B Section 5.3.1.4, AMC 25.1309 Amendment 28 Section 9.b.(1)(iv).
    - Flightcrew error occurs during normal conditions.
        - Those not including the non-normal conditions described below.
    - Flightcrew error occurs when responding to failure conditions.

- Flightcrew error occurs when responding to non-normal conditions (and is also a non-failure condition).
  - An example is another aircraft flight path change leading to a loss of separation with the ownship and then flightcrew error occurs (e.g., TCAS Resolution Advisory and then the flightcrew misinterprets the Resolution Advisory guidance information due to the indication implementation).

Regarding the text “installed equipment must incorporate means to enable the flightcrew to manage errors”.

- The applicant should describe how the installed systems and equipment incorporate means to enable the flightcrew to manage errors. These are termed “mitigations” in this GAMA document. Reference AC 25.1302-1 Section 5-7.a.(2) and AMC 25.1302 Amendment 28 Section 4.5.(a)(2), and also discussed in other sections of those AC / AMC.
- The applicant should assume that flightcrew errors cannot be entirely prevented. Reference AC 25.1302-1 Section 5-7.a.(3)(a), AMC 25.1302 Amendment 28 Section 4.5.(a)(3)(i).

Regarding the text “errors resulting from the kinds of flightcrew interactions with the equipment that can be reasonably expected in service”.

- The applicant should include flightcrew errors that can be reasonably expected in service. The applicant should describe how “reasonably expected in service” is determined. Reference 14 CFR / CS 25.1302(d).
  - “Reasonably expected in service” is described below.
    - “(c) The requirement to manage errors applies to those errors that can be reasonably expected to occur in service from qualified and trained flightcrews. The term “reasonably expected in service” means errors that have occurred in service with similar or comparable equipment. It also means errors that can be predicted to occur based on general experience and knowledge of human performance capabilities and limitations related to use of the types of controls, information, or system logic being assessed.” Reference AC 25.1302-1 Section 5-2.c.(10)(c), AMC 25.1302 Amendment 28 (GM1 25.1302 Section 2.(c)(10)).
      - These flightcrew errors can be predicted via the HEA.
      - These flightcrew errors can be observed during the applicant’s human factors evaluations and tests, during the applicant’s other (non-human factors) evaluations and tests, during the applicant’s other flights (e.g., corporate flights, checkout flights before delivery to customer), during the applicant’s operator flights, or from sources other than the applicant. For the flightcrew errors identified, especially for those identified not part of the human factors evaluations and tests, there may be a need to gather additional data to determine if it was a flightcrew error within the scope of 25.1302 (e.g., video, audio, data logs). It should be reiterated that lack of operational data regarding flightcrew error does not mean the flightcrew error is not valid (i.e., it

could mean that the flightcrew error has not occurred, or occurred but was not document or documented incorrectly). See Section 4 of this document for observed flightcrew error.

- Flightcrew errors that are observed per the bullet above and that are determined to be "reasonably expected in service", these should be included within the HEA (e.g., add to the HEA, or provide more detail to an existing flightcrew error in the HEA).

- Aspects to consider when determining whether a flightcrew error can be reasonably expected in service are described in Section 3.7.

- Overall, the applicant should have a process, method, and criteria to determine a flightcrew error that can be reasonably expected in service.

- Examples of "reasonably expected in service" may be:
  - Fail to execute the task (e.g., forget to retract the landing gear).
  - Task execution incomplete (e.g., move flap control aft one interval instead of two intervals).
  - Task executed in the wrong direction (e.g., turn a knob clockwise instead of counterclockwise).
  - Wrong task executed (e.g., change vertical speed instead of changing altitude).
  - Task repeated (e.g., double tap a touchscreen target to select / deselect).
  - Task executed on wrong interface element (e.g., actuating a control located adjacent to, and similar in design to, the intended control, such as a circuit breaker).
  - Task executed too early (e.g., extend landing gear when speed is greater than the safe extend speed).
  - Task executed too late (e.g., retract landing gear when speed is greater than the safe retract speed).
  - Task executed too much (e.g., turn a knob and stop past the intended setting).
  - Task executed too little (e.g., turn a knob and stop before the intended setting).
  - Misread information (e.g., misread navigation information on a display).
- Examples of not "reasonably expected in service" may be:
  - Actuating a control that is dissimilar in design from the intended control (e.g., actuating a pushbutton when the intended control is a knob, even if they are in the same panel).
  - Actuating a control that is unrelated to the task from the intended control (e.g., actuating a control from the electrical system when the intended control is from the hydraulic system, but unrelated to the task of executing hydraulic failure procedure, even if controls are close to each other).
  - Actuating a control that is distant from the intended control, especially when unrelated to the task (e.g., actuating a control on an overhead panel when the intended control is on a panel in front of the flightcrew).
- It is recommended that the applicant assess a single flightcrew error at a time.

    - The HEA process may help determine which flightcrew errors are “reasonably expected in service” (see Section 3.3).
- The applicant should include the effect of flightcrew errors at the time it occurs and / or later if that is when the effect occurs.
- This GAMA document utilizes a qualitative method to identify flightcrew errors that are reasonably expected in service. The applicant should assume that no validated methods exist to reliably predict flightcrew error probability or all the sequences of events with which they may be associated. If an applicant chooses to use a quantitative approach, the validity of the approach should be established. Reference AC 25.1302-1 Section 5-7.a.(3)(a), AMC 25.1302 Amendment 28 Section 4.5.(a)(3)(i), AC 25.1302-1 Section 5-7.a.(7)(c), AMC 25.1302 Amendment 28 Section 4.5.(a)(5)(iii). Also discussed in AC 25.1309-1B Section 5.3.5.3 and 8.1, AMC 25.1309 Amendment 28 Section 9.b.(5)(iii) and 12.

Regarding the text “This paragraph does not apply to any of the following:”.

- The applicant should not include errors as described below.
    - “(1) Skill-related errors associated with manual control of the airplane;
    - (2) Errors that result from decisions, actions, or omissions committed with malicious intent;
    - (3) Errors arising from a crewmember's reckless decisions, actions, or omissions reflecting a substantial disregard for safety; and
    - (4) Errors resulting from acts or threats of violence, including actions taken under duress.” Reference 14 CFR / CS 25.1302. Also reference AC 25.1302-1 Section 5-7.a.(4), AMC 25.1302 Amendment 28 Section 4.5.(a)(1), AC 25.1302-1 Section 5-2.c.(10)(d), AMC 25.1302 Amendment 28 (GM1 25.1302 Section 2.(c)(10)).
- Consideration should be given to the design of the user interface for AFM procedures when hosted on the installed equipment (e.g., electronic checklist). The HEA should assume that flightcrew procedures (e.g., AFM procedures) are per design. The flightcrew not following procedures (e.g., skipping procedures) may be considered a flightcrew error if a contributing reason for the flightcrew error is the user interface design. This is not a flightcrew error within the scope of 25.1302 if the reason is (1), (2), (3), or (4) above. The flightcrew following procedures that are not correct or not complete is not considered a flightcrew error, and therefore will be given to applicable subject matter expert for incorrect or incomplete documented procedures.

3.2 Perform a Task Analysis

3.2.1 Purpose

A task analysis is performed to define and understand the tasks a flightcrew must complete and the sequence of them to accomplish a goal. These may be physical tasks, like pushing a button, or cognitive tasks, like deciding between alternatives. Many task analysis methods exist, and Stanton et al. (2013) provide high-level guidance on different task analysis methods, including the advantages, disadvantages, validity, and reliability of each, and that information will not be repeated here. The purpose of this section is to capture other considerations for choosing an appropriate task analysis

method, to describe essential characteristics of suitable methods when applied to an HEA, and to describe how task analysis results should be used in the context of an HEA.

3.2.2 Choose a Task Analysis Method

To choose a task analysis method or methods depends on the nature of the task to be used for a subsequent HEA, and consider available resources, task considerations, system considerations, coverage of the HEA objectives, repeatability (reliability), and understandability. Known limitations of the method or how it was conducted should be documented as well as any attempts to mitigate those limitations.

Available Resources

The task analysis method should be feasible to complete within the time and resources available. For example, if a pilot is unavailable for knowledge elicitation, some task analysis methods may not be feasible.

Task Considerations

The nature of the task in question should inform the task analysis method. A task analysis may look quite different for a decision-centered task for selecting an optimal route around convective weather activity compared to interacting with a physical mode control panel.

System Considerations

System complexity and integration influence the selected task analysis method. For example, a keystroke-level task analysis for a highly complex and integrated sub system may result in an unwieldy and brittle assessment. The task analysis method should be feasible to complete within the time and resources available with respect to the system complexity and integration.

Coverage of the HEA Objectives

The objectives of the subsequent HEA may guide the selection of a task analysis method. The proposed task analysis method should address tasks related to the error types of interest, like errors related to physical flightcrew actions (i.e., omission or timing) and/or cognitive errors (i.e., decision-making or judgment).

Repeatability

The task analysis method should be repeatable (reliable), meaning different task analysis teams would produce similar results. Although there will always be interindividual variability in the results, a task analysis method that limits the potential interpretation will lead to more uniform results. The task analysis involves a team of contributors (see Section 2.2). The team should resolve differences in interpretation through discussion and agreement between contributors, and document these decisions for traceability. The team should use expert judgment to be reasonably confident that another team (with adequate qualifications) would produce similar results.

Understandability

The task analysis method should be easily understood by the applicant in general, HEA team specifically, and certification authority. An independent reviewer should be able to follow a logical thread from the system description, assumptions, task preconditions, task boundaries, and defined stop rules to come to a similar conclusion on how the task was represented in the analysis. When used as part of the HEA as a means of compliance, the task analysis should enable certification authorities to make an informed compliance decision. Graphical formats are useful for developing, visualizing, and determining task boundaries and stop rules for the initial task analysis. Shorthand notations, like those suggested by Huddlestone and Stanton (2016), may help declutter graphical depictions. However, depending on the scope of the analysis, a graphical depiction can be difficult to document for certification submission. Tabular or other formats may be used for more concise documentation.

3.2.3 Conduct the Task Analysis

Once an appropriate task analysis method is selected, the task analysis should be conducted according to the prescribed task analysis procedures. Modifications to the procedure may be necessary to adapt to the system or task under analysis. These modifications should be documented appropriately.

Section 2.2 describes the ideal team composition to conduct the analysis. Preferably, the task analysis and HEA should be performed by the same personnel. Some members of the HEA team may not be familiar with formal task analysis methods. These non-specialists should receive training on the task analysis procedures.

The task analysis, as related to the HEA, should include the following for compliance:

- Flightcrew tasks from the flightcrew seated in the pilot seat at the start of the flight through leaving the pilot seat at the end of the flight. These are the tasks within scope of the HEA used for certification (see Section 3.1). The scope of the tasks could be as described below.
    - All flightcrew tasks.
    - Flightcrew tasks to accomplish a general task (e.g., perform an LPV approach). This may include many systems and equipment.
    - Flightcrew tasks utilizing a specific system(s) and equipment (e.g., ROAAS).

Other flightcrew tasks (e.g., pre-flight walkaround the aircraft) can be considered when developing a task analysis, but are not within scope of 25.1302 compliance.

HEA teams may find that some task analysis components are modular and can be reused across other tasks. This may help reduce the complexity of the task analysis. However, the team should be careful during the subsequent HEA to ensure flightcrew errors are assessed according to the specific context in which the modular component is used.

After completing the task analysis, to determine if the task analysis has accomplished its purpose, the HEA team should assess the following questions:

1. Are assumptions, task preconditions, boundaries, and stop rules adequately defined?
2. Does the task analysis stay within the defined scope of assumptions, task preconditions, boundaries, and stop rules?
3. Does the description of goals and tasks include the planned sequence in which they are performed?
4. Do goals, tasks, sub-tasks, and plans contain objective triggers and completion criteria?
5. Is the decomposition and sequences of tasks and sub-tasks logically equivalent to their parent tasks and goals?
6. Is the task analysis sufficiently flexible to account for dynamic task conditions?
7. Does the task analysis identify all tasks relevant to perform the subsequent HEA?
8. Are tasks sufficiently described such that they can be analyzed for potential human errors and their consequences during the subsequent HEA?
9. If the task analysis is to be used to support an HEA as a means of compliance related to flightcrew error management, are tasks sufficiently described to identify sub-tasks and plans that provide the flightcrew a chance to recover from or mitigate errors?

If the team determines the answer to any of the above questions is no, the task analysis should be revised until a satisfactory resolution is achieved.

3.3 Identify Potential Flightcrew Errors

3.3.1 Purpose

The potential flightcrew errors are identified by first choosing a human error taxonomy and then applying the taxonomy to the task analysis.

3.3.2 Choose a Human Error Taxonomy

To choose a human error taxonomy, consider the available resources, coverage, repeatability (reliability), validity, and understandability. The taxonomy is only to be used to identify flightcrew errors. Certain taxonomies include content related to determining likelihood of the error, criticality of the error, and acceptability of the error – those aspects of the taxonomy are not to be used for the HEA as described in this document, because this document provides recommendations for those aspects.

Existing taxonomies (e.g., SHERPA, Human Error Template, HFACS, TRACEr) have been developed for particular industries and contexts. These existing taxonomies might require adjustment and validation for the taxonomy to be pertinent to flight deck design and certification activities. Refer to *Human Factors Methods 2nd Edition* (Stanton et al., 2013) for a list of some taxonomies.

Available Resources
Identifying the flightcrew errors, using the human error taxonomy, should be feasible to complete within the time and resources available.

Coverage
The human error taxonomy should cover the potential errors applicable to the subject of the HEA. Similar to the task analysis coverage of physical and cognitive tasks, the human error taxonomy should cover error modes that are physical and cognitive.

Repeatability
The human error taxonomy should be repeatable (reliable), meaning different HEA teams would produce similar results. Although there will always be interindividual variability in the results, a taxonomy that limits the potential interpretation will lead to more uniform HEA results from the same task analysis. Identifying flightcrew error involves a team of contributors (see Section 2.2). The team should resolve differences in interpretation through discussion and agreement between contributors, and document these decisions for traceability. The team should use expert judgment to be reasonably confident that another team (with adequate qualifications) would produce similar results.

Validity
The human error taxonomy that the applicant chooses to use should have previously been validated and published within a peer-reviewed document (or a slight variation of one to adapt to a particular domain or context). This will facilitate acceptance by the certification authority. Alternatively, a taxonomy that has been developed by the applicant will need to be presented to the certification authority at the earliest possible time in the program for acceptance. The taxonomy may directly refer to a known model or a model of human performance with a theoretically plausible internal structure (Shorrock, 2002) to ensure its validity.

Understandability
The human error taxonomy should be easily understood by the applicant in general, HEA team specifically, and certification authority. An independent reviewer should be able to follow a logical thread from the task analysis to identifying errors to come to a similar conclusion on how the flightcrew error was represented in the analysis. When the HEA is utilized as a means of compliance, it should enable certification authorities to make an informed compliance decision. Graphical formats are useful for developing, visualizing, and determining flightcrew errors as related to the task analysis; however, it can be difficult to document for certification submission. Tabular or other formats may be used for more concise documentation. Graphical or tabular format may be determined by the human error taxonomy used.

3.3.3 Apply the Human Error Taxonomy to Identify Potential Flightcrew Errors

The next step in the HEA is to identify potential flightcrew errors associated with tasks selected per Section 3.2. These potential flightcrew errors are those within scope per Section 3.1 (e.g., flightcrew errors that are reasonably expected in service).

For each flightcrew action task (per the task analysis), each error mode (per the human error taxonomy) should be determined if applicable. Note that each error mode may not be applicable to each flightcrew action task. There may be more than one error mode applicable to a flightcrew action task.

For example, a list of error modes per the Human Error Template (Stanton et al., 2013) are below:

- Fail to execute.
- Task execution incomplete.
- Task executed in wrong direction.
- Wrong task executed.
- Task repeated.
- Task executed on wrong interface element.
- Task executed too early.
- Task executed too late.
- Task executed too much.
- Task executed too little.
- Misread information.

3.4 Describe the Flightcrew Error without Mitigations

The term “without mitigations” means the mitigations as described in Section 3.5 and 3.6 are not considered for this part of the analysis. The flightcrew error occurs and no credit is taken for a means to prevent, correct, and / or manage the flightcrew error.

The purpose to assess the flightcrew error without mitigations is to determine the severity and to compare with the severity with mitigations to determine how much emphasis is put on a mitigation. This provides one way to understand the level of scrutiny needed to validate the availability and effectiveness of the mitigations (as described in Section 3.5). For example, a flightcrew error without mitigations that is Catastrophic (and with mitigations is Major) should have more attention because it is reducing from an unacceptable to acceptable severity. Special attention should be given to the design for flightcrew errors with greater safety consequences to ensure prevention and/or management of such flightcrew error.

In many cases, a baseline flight deck or system design already exists, and the applicant has determined the availability and effectiveness of the mitigations and therefore an analysis of the severity without mitigations may not be needed (see Figure 1).

3.4.1 Describe the Flightcrew Error Scenario without Mitigations

The HEA should describe the sequence of events of the flightcrew error scenario, without use of mitigations, sufficiently to understand the nuances of the scenario. The length and detail of the description may vary based on the complexity of the scenario. This includes the following:

- Phase of flight at the start of the flightcrew error scenario.
- Operational conditions at the start of the flightcrew error scenario. See Section 3.1.2.
- Environmental conditions at the start of the flightcrew error scenario. See Section 3.1.2.

- Flightcrew seated location (one or both pilots seated in the flight deck).
- Flightcrew performed actions (for each pilot, what they are doing), as per the task analysis (e.g., heading change after takeoff).
- Flightcrew error, including the equipment the error occurs on (e.g., incorrect heading was entered on the guidance control panel).
- Initial flight deck and aircraft effects.
- Initial flightcrew perception, decision-making, and response.
- Continuing flight deck and aircraft effects.
- Continuing flightcrew perception, decision-making, and response.
- Outcome of the entire scenario.
    - This should include the unique outcome (e.g., mid-air collision, CFIT, gear up landing), as well as include the text similar to the severity categories (e.g., Catastrophic is hull loss or multiple fatalities of occupants (excluding flightcrew), or fatalities or incapacitation of flightcrew).

The description of the initial and continuing flight deck and aircraft effects, and the flightcrew perception, decision-making, and response, should include the relevant aspects below.

- Flightcrew inherent senses (not using displays, speakers, or other devices). This assumes the flightcrew is onboard the aircraft (not remote pilot).
    - Sight (e.g., pilot natural external visibility detecting changes in aircraft attitude).
    - Hearing (e.g., ambient sound changes due to engine shutoff or changes in thrust).
    - Tactile (touch or feel) (e.g., buffeting, turbulence, vibration, interior temperature changes).
    - Proprioception (e.g., aircraft accelerations and attitude changes).
    - Taste (e.g., smoke).
    - Smell (e.g., smoke).
- Systems and equipment inherent to aircraft design.
    - E.g., means to control aircraft attitude and thrust.
    - Does not include systems and equipment that are mandated per regulation, as these will be considered later in the document when discussing mitigations.

3.4.2 Determine the Flightcrew Error Effect on Aircraft, Occupants excluding Flightcrew, and Flightcrew without Mitigations

For each flightcrew error for each phase of flight, the applicant should determine the flightcrew error effect on aircraft, effect on occupants excluding flightcrew, and effect on flightcrew without mitigations. This document recommends using the same criteria in AC 25.1309-1B Table 4-1 and AMC 25.1309 Amendment 28 Figure 2a.

3.4.3 Determine the Severity of Flightcrew Error without Mitigations

For each flightcrew error for each phase of flight, the applicant should determine the severity of flightcrew error without mitigations. This is based on the effects from Section 3.4.2, and this document recommends using the same criteria in AC 25.1309-1B Table 4-1 and AMC 25.1309 Amendment 28 Figure 2a.

3.5 Identify Mitigations

Mitigations are systems and equipment that prevent flightcrew error, facilitate perception and recovery from a flightcrew error, or facilitate perception and management (not necessarily recovery) from a flightcrew error (also note for this, perception is not required for the flightcrew to manage the effect of the error). Reference AC 25.1302-1 Section 5-7.a.(2) and AMC 25.1302 Amendment 28 Section 4.5.(a)(2).

The applicant first should understand in general the mitigations within scope to be considered, the type of mitigations, and how to determine the availability and effectiveness of the mitigation.

Mitigations to be Considered

The mitigations to be considered include:

- Mandated systems and equipment required by regulation (e.g., TCAS, EGPWS / TAWS).
- Applicant-defined systems and equipment (e.g., physical switch guards, touchscreen confirmation steps, physical separation of controls).
- Note: Practicable mitigations per AC/AMC 25.1302 (economic and operational practicability) should be considered.
    - "The intent of requiring errors to be manageable only "to the extent practicable" is to address both economic and operational practicability. It is meant to avoid imposing requirements without considering economic feasibility and commensurate safety benefits. It is also meant to address operational practicability, such as the need to avoid introducing error management features into the design that would inappropriately impede flightcrew actions or decisions in normal or non-normal conditions. As an example, we do not intend to require so many guards or interlocks on the means to shut down an engine that the flightcrew would be unable to do this reliably in a timely manner commensurate with the severity of the situation." Reference AC 25.1302-1 Section 5-2.c.(10)(i); AMC 25.1302 Amendment 28 Section 4.5.(e)(3); AMC 25.1302 Amendment 28 (GM1 25.1302 Amendment 28 Section 2.(c)(10)(iv)).

Type of Mitigation

The mitigations can be categorized as described below. The categories below are provided to aid in identifying the mitigations; however, the mitigation type ID (e.g., 1a) does not necessarily need to be stated in the HEA.

Table 3 – Mitigation Type

Mitigation Type	Definition	Example
1a	The flightcrew error occurs (or flightcrew attempts to make the error), but the mitigation prevents the flightcrew error from adversely affecting the aircraft. This may be to disallow the flightcrew input or stop the propagation of the effect of the flightcrew input. This affects the severity of the flightcrew error.	Electrical or mechanical interlocks. E.g., logic that prevents the thrust reverse to be deployed in air or logic that prevents the landing gear to be retracted on ground. There may be feedback that the flightcrew input is disallowed. CRM to prevent the flightcrew error. E.g., one pilot checks with the other pilot before making the input.
1b	The likelihood of the flightcrew error occurring is reduced due to the flight deck design. This affects the likelihood of the flightcrew error occurring. Refer to Section 3.7 for consideration of this mitigation.	Shape and color coding of physical controls, physical separation of controls, dual and/or non-intuitive operation, confirmation steps, or a physical guard over a switch.
2	The flightcrew error occurs, and the mitigations provide a means for the flightcrew to perceive, make a decision, respond, and correct the flightcrew error. This affects the severity of the flightcrew error.	Perceive indications, annunciations, alerts (visual, aural, tactile). Correct by undo functions in software. CRM to perceive the flightcrew error. E.g., one pilot makes the error, and the other pilot perceives the error.
3	The flightcrew error occurs, and the mitigations provide a means for the flightcrew to manage the effects of the flightcrew error. The flightcrew error cannot be undone or can only be partially undone. This affects the severity of the flightcrew error.	Flightcrew utilizes the flight deck as designed.

Availability and Effectiveness of the Mitigation

When identifying mitigations, it should be determined whether it is available and effective, as described below.

- The mitigation will be available to be used. The mitigation needs to meet a threshold of availability (failure probability; whether can dispatch with it failed). The applicant should provide a rationale for determining availability. One way is to state that there is more than one mitigation and therefore it would be expected that at least one is available to be used (need to consider MMEL).
- The mitigation can and will be used by the aircraft (automation) or flightcrew. If there is more than one mitigation, at least one will be used. Aspects to consider is that the mitigation does not require exceptional pilot skill / alertness / strength and is usable in the time needed for that specific flightcrew error scenario.
- The mitigation will result in the reduced severity as defined by the HEA. Describe the flightcrew error scenario with mitigation and the final outcome to the aircraft as stated in Section 3.6, to make it obvious to the reader how the mitigation leads to the outcome and how that relates to the severity.

3.6 Describe the Flightcrew Error with Mitigations and Determine if Acceptable

After identifying the mitigations, describe the flightcrew error with mitigations. From this description, the effect on aircraft, occupants excluding flightcrew, and flightcrew can be determined, and the related severity can be determined.

Note that only Mitigation Type 1a, 2, and 3 reduce the severity of the flightcrew error. Mitigation Type 1b can, and typically is, considered during design; however, it is not utilized to determine the severity of the flightcrew error.

3.6.1 Describe the Flightcrew Error Scenario with Mitigations

The HEA should describe the sequence of events of the flightcrew error scenario, with use of mitigations, sufficiently to understand the nuances of the scenario. The length and detail of the description may vary based on the complexity of the scenario. This includes the following:

- Phase of flight at the start of the flightcrew error scenario. Same as described in Section 3.4.1.
- Operational conditions at the start of the flightcrew error scenario. See Section 3.1.2. Same as described in Section 3.4.1.
- Environmental conditions at the start of the flightcrew error scenario. See Section 3.1.2. Same as described in Section 3.4.1.
- Flightcrew seated location (one or both pilots seated in the flight deck). Same as described in Section 3.4.1.
- Flightcrew performed actions (for each pilot, what they are doing), as per the task analysis (e.g., heading change after takeoff). Same as described in Section 3.4.1.
- Flightcrew error, including the equipment the error occurs on (e.g., incorrect heading was entered on the guidance control panel). Same as described in Section 3.4.1.

- Initial flight deck and aircraft effects. With use of mitigations.
- Initial flightcrew perception, decision-making, and response. With use of mitigations.
- Continuing flight deck and aircraft effects. With use of mitigations.
- Continuing flightcrew perception, decision-making, and response. With use of mitigations.
- Outcome of the entire scenario. With use of mitigations.
    - This should include the unique outcome and may be described using text from the outcome without use of mitigations (e.g., maintained aircraft separation [and no mid-air collision], altitude change and then recovery to prevent loss of aircraft separation, avoidance of CFIT, normal gear down landing (or go-around)), as well as include the text similar to the severity categories (e.g., Major is significant increase in flightcrew workload, among other criteria).

The description of the initial and continuing flight deck and aircraft effects, and the flightcrew perception, decision-making, and response, should include the relevant aspects below.

- Flightcrew inherent senses (not using displays, speakers, or other devices). This assumes the flightcrew is onboard the aircraft (not remote pilot).
    - Sight (e.g., pilot natural external visibility detecting changes in aircraft attitude).
    - Hearing (e.g., ambient sound changes due to engine shutoff or changes in thrust).
    - Tactile (touch or feel) (e.g., buffeting, turbulence, vibration, interior temperature changes).
    - Proprioception (e.g., aircraft accelerations and attitude changes).
    - Taste (e.g., smoke).
    - Smell (e.g., smoke).
- Systems and equipment inherent to aircraft design.
    - E.g., means to control aircraft attitude and thrust.
- Identified mitigations (per Section 3.5).

3.6.2 Determine the Flightcrew Error Effect on Aircraft, Occupants excluding Flightcrew, and Flightcrew with Mitigations

Same aspects as described in Section 3.4.2, now considering with mitigations. For each flightcrew error for each phase of flight, the applicant should determine the flightcrew error effect on aircraft, effect on occupants excluding flightcrew, and effect on flightcrew with mitigations. This document recommends using the same criteria in AC 25.1309-1B Table 4-1 and AMC 25.1309 Amendment 28 Figure 2a.

3.6.3 Determine the Severity of Flightcrew Error with Mitigations

Same aspects as described in Section 3.4.3, now considering with mitigations. For each flightcrew error for each phase of flight, the applicant should determine the severity of flightcrew error with mitigations. This is based on the effects from Section 3.6.2, and this document recommends using the same criteria in AC 25.1309-1B Table 4-1 and AMC 25.1309 Amendment 28 Figure 2a.

3.6.4 Determine if the Severity of Flightcrew Error with Mitigations is Acceptable

The applicant should identify the highest severity classification for each flightcrew error with mitigations considering all phases of flight (e.g., even if one phase of flight is rated Major, then Major is the severity to use).

The criteria to determine if the severity of flightcrew error with mitigations is acceptable is:

- If the highest severity of flightcrew error with mitigations is No Safety Effect, Minor, or Major, then this is Acceptable: This achieves Continued Safe Flight and Landing required per AC 25.1302-1 Section 5-7.a.(2)(b) and AMC 25.1302 Amendment 28 Section 4.5.(a)(2)(ii). There is no need for additional or modified mitigations. The HEA is done for this flightcrew error.
- If the highest severity of flightcrew error with mitigations is Hazardous or Catastrophic, then this is Not Acceptable: This does not achieve Continued Safe Flight and Landing required per AC 25.1302-1 Section 5-7.a.(2)(b) and AMC 25.1302 Amendment 28 Section 4.5.(a)(2)(ii). There is a need for additional or modified mitigations, or changes so this flightcrew error is no longer within scope of the HEA.
    - If all practicable mitigations have been considered and the severity is Hazardous or Catastrophic, then the applicant may consider likelihood of the flightcrew error occurring (see Section 3.7).

3.7 Consider the Likelihood of Flightcrew Error with Mitigation Type 1b

If the severity of flightcrew error with mitigations is Not Acceptable (Hazardous or Catastrophic per Section 3.6.4) using Mitigation Type 1a, 2, 3, then the applicant can consider Mitigation Type 1b.

The criteria to determine if the flightcrew error itself is acceptable, considering Mitigation Type 1b is:

- If the highest likelihood of flightcrew error with Mitigation Type 1b, considering all phases of flight, is not “reasonably expected in service”, then this is Acceptable. There is no need for additional or modified mitigations of Type 1b.
- If the highest likelihood of flightcrew error with Mitigation Type 1b, considering all phases of flight, is “reasonably expected in service”, then this is Not Acceptable. There is a need for additional or modified mitigations of Type 1b, or changes so this flightcrew error is no longer “reasonably expected in service”.

The aspects described below may help an applicant determine whether or not a flightcrew error is “reasonably expected in service”. Also see Section 3.1.2.

Examples of aspects increasing the likelihood of the flightcrew error occurrence include the following:

- User interface characteristics leading to error opportunities such as hidden function, or inconsistency in display-control and alerting, similar controls (shape, types) in close proximity which can be operated blindly, inconsistency from flight deck philosophy, no label, high density of information, clutter.
- Type of task: highly complex, seldomly practiced tasks, several tasks requiring to be accomplished in parallel, excessive force or precision required.

- Level of human-automation integration: monitoring automation, complexity of the automation.
- Task interruption or distraction in the workflow.
- Time pressure or duration: short time to accomplish the task or several tasks.
- Workload: high workload or low workload leading to boredom.
- Procedure: high complexity (several decision trees, lengthy procedure, complex tables) or low clarity.
- Environment: high vibration, distracting or excessive noise or dynamic and busy airspace environment.
- Poor CRM: complex cooperation or collaboration. Difficult communication anticipated.
- Memory items.
- Weak correlation between the controls-information versus the workflow.
- Previous incidents or data show similar error types or common design-related error (substitution, reversal, mode, adjustment, omission, etc.).
- Habits, expectation bias, channeled attention.

Examples of aspects decreasing the likelihood of the flightcrew error occurrence include the following:

- Presence of mitigation type 1b and its high quality (Refer to Section 3.5).
- Human Machine Interface: simple, intuitive, and non-ambiguous.
- Simple and intuitive task.
- Simple and clear procedure.
- Consistent and coherent system interface with the overall flight deck philosophy.
- Highly trained procedure or operation.
- Flightcrew action prompting or flightcrew action reminders are available.
- Flightcrew error requires two consecutive non-routine actions to take effect.

4 Observed Flightcrew Error

Flightcrew errors observed in evaluations, tests, and in service can be used to inform the HEA. These can identify potential flightcrew errors and validate aspects of the flightcrew error in the HEA. The applicant should make a determination if the flightcrew error is “reasonably expected in service”. If the error occurs in an evaluation or test, or in service, it does not automatically mean the flightcrew error can be “reasonably expected in service”. The context of the flightcrew error scenario affects that determination, such as if the flightcrew was adequately qualified (which they may not be for early development evaluations), if the design item(s) was functioning properly, and if the flightcrew were following procedures (e.g., sterile flight deck), etc.

4.1 Evaluations and Tests

For evaluations and tests with the intent to collect data other than human factors (e.g., proper functioning, aircraft performance), the applicant may choose to collect flightcrew error data. The HEA team should understand the setup to the evaluation or test, and the flightcrew error scenario. In general, gather the same data that is defined in the HEA. The HEA team may consider interviewing the flightcrew, providing a data sheet for the flightcrew to complete, and / or reviewing the data (e.g., video, audio recording).

For evaluations and tests with the intent to collect data related to human factors, more detail is provided below.

Human factors evaluations and tests may be performed in laboratories, simulators, prototype aircraft, test aircraft, production aircraft, or customer aircraft. There are several methodologies to perform evaluations and tests: part-task laboratory / simulator evaluations, full-flight evaluations / tests with single or multiple flightcrews, simulated scenario evaluations with an external observer, etc. AC 25.1302-1 and AMC 25.1302 Amendment 28 contain guidance material on the selection of the most appropriate methodology based on the required level of scrutiny.

These evaluations and tests are typically performed as part of data collection for many aspects of the flight deck, not specifically only for flightcrew error. These can provide useful data because the HEA team personnel, or other human factors members of the team, are conducting the evaluation or test. Data is readily available through flightcrew interviews and possibly video/audio recording. However, these are resource-consuming activities and must be planned prudently. The goal is to fully understand the flightcrew error scenario, from the conditions in place when the error occurred, through the flightcrew error itself, to the outcome. The aim is not to derive statistical data on flightcrew error probability

Evaluations and tests, in regard to flightcrew error, can, but are not required to, be used to confirm novel design item behaviors, where the design items do not have a proven service history for that kind of operation or represent a new or unusual means for flightcrew interface with a system or equipment. For example, modifying an aircraft with conventional instrument panels (gauges and dials) to integrated display systems (“glass cockpit”).

There are design items that have historically used evaluations and tests to confirm HEA results. For example, validation of some Automatic Flight Control System (AFCS) assumptions in FHAs is required to be performed by simulator / flight tests, as per regulation 25.1329 and guidance material AC 25.1329-1C.

4.2 Company Flights (not for Evaluations or Tests) and In-Service Operations

Company flights not intended for evaluations or tests include maintenance flights, production check flights (before customer delivery), flights to airshows, company personnel transport, etc. In-service operations, in this context, include customer operator flights and may include non-applicant aircraft model flights. The applicant may choose to collect flightcrew error data from these flights. For data collected from these flights, the HEA team should understand the flightcrew error scenario. In general, gather the same data that is defined in the HEA. Depending on if this is a company flight or customer operator flight, there may be differences between personnel and data access. The HEA team may consider interviewing the flightcrew, providing a data sheet for the flightcrew / operator to complete, reviewing the data (e.g., video and audio recording), or reading the incident / accident report.

Service experience can be one of the most valuable sources of feedback about potential design vulnerabilities and flightcrew errors. Most organizations have active in-service safety / continued airworthiness processes that may operate separately from the design engineering groups. These processes can offer design engineers direct opportunities to learn about whether the flightcrew assumptions and expectations are valid, and often reveal surprising ways pilots interpret indications, make decisions, and effect control. It is recommended that organizations find ways to ensure appropriate feedback from in-service safety findings and observations.

Additional sources of service experience include incident repositories such as the Aviation Safety Reporting System (ASRS) and the Flight Safety Foundation SKYbrary, and industry groups such as research organizations and government safety boards often release deep analyses on topics such as takeoff performance errors, loss of control, and pilot responses to alerts that can also be useful to either validate or challenge traditional design assumptions. In some cases, incidents that occur in another manufacturer’s fleet may still inform an ongoing flightcrew human error analysis when the system or function under consideration is common between the two manufacturers.

Appendix A. Abbreviations and Acronyms

AC	Advisory Circular
AFCS	Automatic Flight Control System
AFM	Aircraft Flight Manual
AMC	Acceptable Means of Compliance
Amdt.	Amendment
ANAC	Agência Nacional de Aviação Civil of Brazil
ARP	Aerospace Recommended Practice
ASRS	Aviation Safety Reporting System
ATC	Amended Type Certificate
CFIT	Controlled Flight Into Terrain
CFR	Code of Federal Regulations
CRM	Crew Resource Management
CS	Certification Specification
EASA	European Union Aviation Safety Agency
EGPWS	Enhanced Ground Proximity Warning System
FAA	Federal Aviation Administration
FDHFWG	Flight Deck Human Factors Working Group (GAMA)
FHA	Functional Hazard Assessment
GAMA	General Aviation Manufacturers Association
HEA	Human Error Analysis
HFACS	Human Factors Analysis and Classification System
IFR	Instrument Flight Rules
LPV	Localizer Performance with Vertical Guidance
MMEL	Master Minimum Equipment List
POF	Phase of Flight
QRH	Quick Reference Handbook
RNP	Required Navigation Performance
ROAAS	Runway Overrun Awareness and Alerting System
SAE	SAE International
SHERPA	Systematic Human Error Reduction and Prediction Approach
STC	Supplemental Type Certificate
TAWS	Terrain Awareness and Warning System

TC	Type Certificate
TCAS	Traffic Alert and Collision Avoidance System
TRACEr	Technique for the Retrospective and Predictive Analysis of Cognitive Errors
VFR	Visual Flight Rules

Appendix B. References

General Aviation Manufacturers Association. (2023). Boeing 737 MAX related reports & recommendations and their impact on human factors. *GAMA Publication #21*.

Huddlestone, J. & Stanton, N. (2016). New graphical and text-based notations for representing task decomposition hierarchies: Towards improving the usability of an ergonomics method. *Theoretical Issues in Ergonomics Science, 17*(5-6), 588-606.

Shorrock, S. T. (2002). Error classification for safety management: Finding the right approach. *In Proceedings of a Workshop on the Investigation and Reporting of Incidents and Accidents (IRIA 2002)*, 17th to 20th July.

Stanton, N., Salmon, P., Rafferty, L., Walker, G., Baber, C. & Jenkins, D. (2013). *Human factors methods: A practical guide for engineering and design* (2nd ed.).

Appendix C. HEA Worksheet Example

Below is an example of an HEA Worksheet. This is a suggestion only.

The example table below is organized to describe the same task, sub task, and error mode for each phase of flight (and therefore, these cells are merged across the phases of flight for ease of reading).

The columns are related to the sections within this document (e.g., Description of the Flightcrew Error Scenario is related to Section 3.4.1 and 3.6.1).

For HEA ID X.Y.Z:
X = Same task and sub task. If Not Applicable for a certain phase of flight, then make that obvious (e.g., state Not Applicable, gray out the row).
Y = Same error mode. If Not Applicable for a certain phase of flight, then make that obvious (e.g., state Not Applicable, gray out the row).
Z = Phase of flight.

Table 4 – HEA Worksheet Example

						Without Mitigations						Mitigations	With Mitigations								
HEA ID	Phase of Flight (POF)	Environmental and Operational Conditions	Task	Sub Task	Error Mode	Description of the Flightcrew Error Scenario	Effect on Aircraft and Related Severity	Effect on Occupants (Excluding Flightcrew) and Related Severity	Effect on Flightcrew and Related Severity	Highest Severity for each POF	Highest Severity for all POF		Description of the Flightcrew Error Scenario	Effect on Aircraft and Related Severity	Effect on Occupants (Excluding Flightcrew) and Related Severity	Effect on Flightcrew and Related Severity	Highest Severity for each POF	Highest Severity for all POF	Acceptable for all POF (if Major or less)	Acceptable for all POF (if higher than Major but the flightcrew error is not reasonably expected in service – provide justification)	Ref.
1.1.1	Startup																				
1.1.2	Taxi to Takeoff																				
1.1.3	Takeoff																				
1.1.4	Climb																				
1.1.5	Cruise																				
1.1.6	Descent																				
1.1.7	Approach																				
1.1.8	Landing																				
1.1.9	Taxi to Parking																				
1.1.10	Shutdown																				

Appendix D. Contributors

Ratan Khatwa - Chairman GAMA Flight Deck Human Factors Working Group, Boeing Company

Core Task Team

Company	Participant
Boeing	Ratan Khatwa – Chairman Victor Riley
Bombardier	Nami Bae Benoit Ouellette
Collins	Olivia Villamagna – Task Co-Lead
Embraer	Marcelo Moreira
GAMA	Andy Phillips
Garmin	Adam Lary
Gulfstream	Katarina Morowsky
Honda Research Institute	Tim Buker – Task Co-Lead
Honeywell	Gernot Konrad
Moog	Stephanie Smith

Flight Deck Human Factors Working Group

Company	Participant
Boeing	Ratan Khatwa – Chairman Victor Riley
Bombardier	Nami Bae Benoit Ouellette
Collins	Leslie Stratton Olivia Villamagna
Embraer	Eduardo Menini Marcelo Moreira
GAMA	Andy Phillips
Garmin	Adam Lary Isabella Piasecki
Gulfstream	Katarina Morowsky Gilvan Da silva
Honda Research Institute	Tim Buker
Honeywell	Gernot Konrad
Joby Aviation	Mark Nikolic
Moog	Stephanie Smith
Textron	Andrew Lake Greg Potter