Federal Aviation Administration

SAFETY FRAMEWORK FOR AIRCRAFT AUTOMATION

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Foreword

Aviation is on the precipice of an explosion in automation capabilities, fueled by the continued advance of computing and sensor capability, access to data, innovations in artificial intelligence, and new air mobility and drone operating models. These innovations have the potential to further reduce risks in aviation and to enable new business models, while introducing new risks from highly complex systems and changes to pilot tasks and qualifications.

We have developed this Framework to explain our guiding principles to foster safe innovation in this area. These guiding principles build on decades of experience with automation in transport aircraft. The Framework also provides terminology to align automation with our existing policies for aircraft certification and pilot ratings. The terminology is intended to facilitate subsequent discussions for various automation applications to determine appropriate system and operational requirements.

This Framework is offered to the aviation community as an initial step to foster the safe advancement and use of automation in all aircraft and operations. We look forward to working with the aviation industry and other aviation regulators to apply this Framework to opportunities such as Advanced Air Mobility and to refine the Framework.

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Purpose

The purpose of this document is to provide a common framework for discussing the criteria and approval of highly automated aircraft systems, the certification of aircraft, and the pilots and operators that use such aircraft. This framework encompasses all types of aircraft and operations, including but not limited to small (general aviation) aircraft, transport aircraft, drones, and advanced air mobility (AAM) aircraft with onboard or remote pilots.

This document provides key concepts, and terminology used to address these topics. The document describes challenges related to ensuring safe operations and provides guiding principles to address these challenges. This framework will inform the development of roadmaps or implementation activities for specific automation initiatives, such as automation in remotely piloted AAM.

Background and Key Terms and Concepts

While a variety of stakeholders across government, academia, and industry are actively developing and debating lexicon for aspects of the automation topic, there is currently no standardized terminology for automation in aviation. This document uses the key terminology and definitions described below.

A key concept in this framework is that specific tasks are automated, rather than the aircraft itself. Aircraft designers have introduced automation for a wide variety of tasks, and it is important to be specific about what task or set of tasks is being automated. Broad terms such as *autonomous aircraft* are not conducive to defining an appropriate set of requirements or approval method. It may be necessary to deconstruct high-level tasks, such as navigating the aircraft, into subordinate tasks in order to define appropriate automation and pilot requirements.

The criteria for approving automated systems, and the pilots using those systems will differ according to the *type* of task. Examples of types of tasks include:

1. **Control Automation:** Automation for control tasks refers to automation related to controlling some aspect of the aircraft flight, such as an autopilot, autothrottle, or fuel management function.
2. **Information Automation:** Automation for information tasks refers to automation for the calculation, integration, and presentation of information. Examples of tasks utilizing information automation include aircraft performance determination, fuel calculation or aircraft system health assessment using flight deck displays or electronic flight bags.

Various organizations have proposed levels of automation to address the extent to which a particular control task is automated.[1] Other organizations have recommended a functional breakdown of automation instead of discrete levels.[2] This document builds on those concepts to adopt terms that distinguish the automation and pilot implications for the automated task. This distinction has value in determining the integrity and availability requirements for the automated systems and is essential for considering the impacts to pilot qualification. It is important to note that automation may reduce pilot workload during normal operations, but it can also increase workload and complexity in demanding situations, including managing failures. Another key operational consideration is that a pilot's proficiency is affected by how often they perform any given task. This issue can be exacerbated if the system design and overarching philosophy are not well understood by the pilot or operator.

[1] Joint Authorities for Rulemaking on Unmanned Systems (JARUS), European Union Aviation Safety Agency (EASA) Artificial Intelligence (AI) Roadmap, General Aviation Manufacturers Association (GAMA) Electric Propulsion& Innovation Committee (EPIC), SAE Taxonomy and Definitions for Terms Relating to Driving Automation Systems for On-Road Motor Vehicles.

[2] ASTM Autonomy Design and Operations in Aviation: Terminology and Requirements Framework, General Aviation Manufacturers Association (GAMA) A Rational Construct for Simplified Vehicle Operations

This document proposes four automation categories to provide a basis for grouping appropriate requirements for the automation and the pilot from a task-based perspective. These categories are described in Table 1. Since automation refers to specific tasks or sets of tasks, any discussion of the automation must define which tasks are automated and the extent to which the task is automated. The automation category is a significant factor in defining the reliability requirements for the system(s) and the required qualifications of the pilot, variety of operating modes, and combinations of the automated systems.

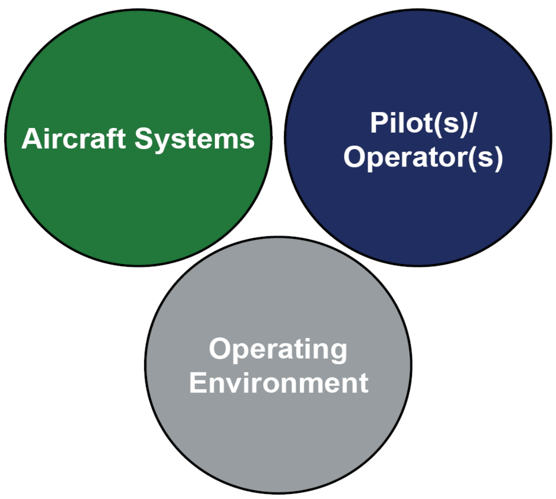
<table>
<tr><th>Category</th><th>Full Definition</th><th>Automation can Perform the Task</th><th>Pilot Monitoring/ Supervision Required</th><th>Pilot Can Perform the Task</th></tr>
<tr><td>Assistive</td><td>Automation that assists the pilot in performing the task.</td><td>No</td><td rowspan="2">Yes</td><td rowspan="3">Yes</td></tr>
<tr><td>Supervised</td><td>Automation that must be monitored by the pilot while performing the task, so the pilot can recognize and mitigate undesired automation performance or take over the task. Supervised automation must also enable the pilot to perform the task.</td><td rowspan="3">Yes</td></tr>
<tr><td>Alternative</td><td>Automation that can perform the task without pilot supervision while it is operating. Alternative automation may not work under all possible operational conditions (the pilot performs the task under such conditions).</td><td rowspan="2">No</td></tr>
<tr><td>Autonomous</td><td>Automation that performs the task without pilot supervision, and without any means for the pilot to perform the task. Autonomous automation must reliably identify and execute appropriate behaviors for all possible operational conditions, since there is no intervention that can be taken for that task.</td><td>No</td></tr>
</table>

Table 1 Automation Categories

Together, the automated tasks form the automated operation. Pilots must understand and manage the entirety of the operation, the aircraft, and its varied automated systems. The operational complexity of the aggregate of all automated tasks can become a significant risk, as the pilot must apply knowledge of the operation and the automated systems to predict system behavior with sufficient time to intervene if required.

Another key concept is the framework for responsibility. Considerable effort goes into establishing the aircraft's safe ability to support the intended operation in the intended environment. Similarly, pilots are trained and qualified to operate the aircraft for their intended operations and environments. It is the responsibility of the Original Equipment Manufacturer (OEM) to design, develop and produce systems to perform their intended function. It is the responsibility of the pilot to safely conduct specific operations, given the aircraft systems and the actual operating environment. Certificated operators have additional responsibilities to support the pilot, prior to and during the operation. The OEM responsibility can be transferred to other entities if they modify the system, and the pilot (and operator as appropriate) maintain the aircraft to the approved design and ensure it is in a condition for safe operation.

When evaluating and approving automated systems for aircraft, the Federal Aviation Administration (FAA) and applicants must consider the task(s), including safety criticality, performance criteria, complexity and interaction with other tasks, pilot/operator requirements, and the environment (see Figure 1). The designer must decide what role(s) pilots or operators will have and ensure that the role(s) can be accomplished by a qualified pilot or operator. This may involve defining additional requirements for pilot qualification, such as those under an applicable type rating. Consideration of these requirements should include the acceptability of pilot tasks, qualifications, and responsibilities. When approving an automated system, all aspects outlined in Figure 1 must be addressed.



Aircraft Systems includes everything that is the aircraft integrator's responsibility:
• Aircraft
• Ground equipment (if applicable)
• Third-party (external) systems and services (if applicable)

Aircraft System Designer: Design the aircraft system to foster human success in the anticipated operational environment

Pilot(s)/Operator(s)
• Operate the aircraft system as intended
• Manage events outside of the anticipated operational environment

Pilot/Operator: The qualified individual responsible for a particular flight

Operating Environment
• Weather, traffic, operating rules, ATC, etc.

Figure 1 Aircraft, Pilots/Operators, and Operating Environment

When seeking to operate an aircraft with highly automated systems or a new and novel pilot/operator-system interaction, the pilot or operator must consider the aircraft within the operational environment. The pilot or operator must decide on flight crew procedures, considering what automation is available, the automation operating philosophy for the operator, and the operational environment. The design of the operation itself may impose additional qualification requirements on the pilot beyond those imposed through aircraft design, such as airspace operations and memorizing company-specific operating procedures. When approving an operator, all aspects outlined in Figure 1 must be addressed.

The operation and environment, represented by the third circle in Figure 1, is not a directly regulated entity. Instead, it is controlled through the limitations of the operator's intended operation, which also reflect constraints imposed by the aircraft design. However, aircraft in operation occasionally encounter conditions beyond those preconceived boundaries. This can occur due to external factors that are not well understood or predicted, inadequately controlled, or due to unforeseen events outside the scope of the original aircraft and operator approval. The pilot must manage these situations with the capabilities available to them.

Challenges

The aviation industry has been expanding the use of automation for several decades, a trend that affects every segment of the industry. This has resulted in improved safety against risks such as loss of control, mid-air collisions, and controlled flight into terrain. However, the use of aircraft automation has also introduced new risks that must be managed and challenges that must be addressed. Challenges include:

- Manufacturer decisions on what and how to automate have led to some aircraft having complex mode selection, awareness, and alerting that can be challenging for the pilot to manage.
- The design of automated systems is based on assumptions about aircraft, pilots, and operating conditions. It is challenging for automation designers to anticipate and account for the variety of aircraft, pilot, and operating environment conditions that are encountered in real operations.
- Increasing the use of automated systems increases the potential for over-reliance on those systems.
- Novel aircraft automation introduces additional challenges for evaluation methods to maintain the expected level of safety. For example, traditional methods for assessing system failures do not consider the range of pilot behavior and performance.
- Pilots traditionally bring resilience to the system, managing situations that occur outside what the aircraft designer and operator may have anticipated, including unanticipated failures, environments, and operations. Achieving a sufficient level of system comprehension to diagnose these conditions can be very complex.
- Use of automated systems changes pilot cognitive demands. Additionally, the variety of automated systems and capabilities among different aircraft may result in new experience, knowledge, and skills to be addressed in type ratings and pilot qualification(s).
- Developing appropriate evaluation criteria will be critical to assess pilot(s) knowledge and skills for use of the automated system(s) and failure modes, and the ability to monitor and intervene when needed.
- Pilots who routinely use automated systems may not have sufficient practice to maintain the knowledge and skills to complete tasks when the automation is not available. For example, FAA has encouraged that manual flight operations knowledge and skills are maintained.[3]

The industry trend to automate tasks is expected to accelerate with the availability of new sensor and processing technologies, including machine learning. Some new entrants, such as large-scale Powered Lift electric vertical take-off and landing (eVTOL) operations, are predicated on the successful implementation of automation to reduce the traditional workload of a pilot and enable operations. Additional new operations, such as unmanned aircraft operations, are predicated on some tasks becoming autonomous and may involve new concepts of a group of people managing the operation of a larger group of aircraft (also referred to as "one pilot to many" aircraft operations). These concepts remove some responsibilities from the pilot, which introduces additional challenges:

[3] Safety Alerts for Operators (SAFO) 13002, SAFO 17007, Advisory Circular (AC) 120-123 Flightpath Management

- Defining automation requirements for what were traditionally human tasks, such as see-and-avoid of other aircraft.
- When pilot tasks are autonomous, it becomes difficult, or impossible, for the pilot to manage these conditions.
- Pilot qualification assumes that pilots need knowledge and skills to manage the automation. There is no current method to determine knowledge and skills which may no longer be required.
- Novel automated functions impact the concept of operations and have implications for qualification of the equipment, operational procedures, and training of human operators. The evaluation of the automated functions may need to consider implications for different use cases, operational concepts, and environmental conditions as an integrated system.

Guiding Principles

The following guiding principles are proposed to inform the development and use of criteria and the approval processes for highly automated aircraft.

- **Apply the safety continuum:** The rigor with which the safety assurance of automation is addressed should be commensurate with the acceptable risk for the operation.
- **Allow applicant-led innovation:** Recognizing the pace of technological development and the variety of potential automation applications, FAA should allow applicants to pursue automation concepts of their choosing, while still assuring the appropriate level of safety. Applicants may also work together to develop consensus-based industry standards.
- **Work within the existing aviation regulatory system:** Existing regulatory material should be utilized when possible and small changes should be considered where necessary to minimize unintended consequences to the rest of the aviation community. Also to be considered is the impact on the regulatory responsibilities of the aircraft designer, pilot, and operator. Regulators should align and/or harmonize when feasible.
- **Avoid personification of the automated system(s):** Automation is a tool, not a person. Personification of the system can lead to incorrect mental models of the system's capabilities. Use appropriate terminology to reinforce this reality to the designers, pilots and operators and avoid personifying terminology such as "teaming" and "assistant." This principle is outlined in the FAA Roadmap for Artificial Intelligence (AI) Safety Assurance[4], as AI-based systems are a form of automation.
- **Consider the effects of automation on pilot workload:** The use of automation may reduce the workload in some circumstances and increase workload in other situations. Automation should not adversely affect the pilot's workload.
- **Apply the principle of aircraft design responsibility to associated elements:** Aircraft system descriptions should account for functionality that is off-board the aircraft, such as operational infrastructure, ground control stations, third party service providers, etc. There must be a system integrator who takes responsibility for the entire aircraft system.
- **Be aware of applicant responsibility for aircraft system automation:** The aircraft applicant is responsible for designing a safe system for the expected pilot performance and behavior and the expected operational scenarios (with a rigor commensurate with the safety continuum as noted above). This involves:
  - The type of system and its tasks/functions, including what is being automated
  - How the pilot will interact with and manage it during operations
  - System capabilities and limitations
  - Consideration of operational implications, including but not limited to training, procedures, operational policies, and potential skill degradation (both psychomotor and cognitive)
- **Promote a consistent set of pilot qualification standards:** Qualifying pilots is more costly if there is significant variation among aircraft, and the potential negative transfer for any pilot moving from one aircraft to another will need to be mitigated. This tradeoff extends to operating paradigms which define pilot responsibilities. The aircraft development and operator community should consider this tradeoff and lead the development of common core pilot and operational expectations for various categories of new aircraft or operations.
- **Promote design and operational simplicity:** Promote simplicity by reducing the variety of automation modes, settings and combinations that must be managed by the pilot. This simplicity should not mask complexity of the underlying system; the behavior of the

[4] FAA Roadmap for Artificial Intelligence (AI) Safety Assurance

system from the pilot’s perspective should be predictable and unambiguous. A designer may include adopting an automation philosophy, unifying automated tasks into a few high-level tasks, and adopting autonomous control automation.

- **Promote operational resilience through design and operational monitoring:** Aircraft designers should consider what information and controls are required by the pilot to manage any operational conditions, including those unforeseen. Aircraft designers and operators should monitor operations and environmental conditions to identify, learn, and mitigate any operational conditions that were unforeseen by the designer.
- **Address existing and novel security threats:** Increasingly automated aircraft systems must be sufficiently reliable and resilient to existing and novel security threats.