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WHITE PAPER

A Safety Intent-Based Application of Part 23 “Pilot” and “Flightcrew” Requirements for Uncrewed Aircraft

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Introduction

Discussion of Scope

Automation is increasingly being introduced into aircraft design, development, operation, and certification. To facilitate the precise work of showing compliance with regulatory design standards, having a clear understanding of regulatory language is critical.

This white paper addresses how designers of highly automated, remotely piloted, optionally piloted, and/or uncrewed aircraft can meet and show compliance with the safety intent of existing airworthiness standards that use the words "pilot" or "flightcrew" and show compliance with these certification basis requirements.

These two words are used throughout existing airworthiness or "type design" regulations dealing with the physical requirements of the aircraft and the ability of that type design to result in repeatable and predictable performance. For uncrewed aircraft, such performance must be accomplished within the control volume of the aircraft itself (e.g., by aerodynamic design or intended functions) rather than through assumed pilot functions. The design requirements that an aircraft developer may identify as necessary in order to achieve operational approval for an aircraft and concept of operation are outside the scope of this paper. Their demonstration would be covered through the showing of compliance for intended function performance across the proposed operational envelope.

It is fully acknowledged that airworthiness is one component of the overall approval ecosystem. Airman certification (including for remote pilots) and operational approval are necessary components of both aviation safety and regulator oversight and must be accomplished prior to operationalization of an aircraft design. While outside the scope of this document, the implications and evolution of the connections between the components of the different aspects of the safety ecosystem due to increasing autonomy provide a rich area for future work.

This document specifically addresses the design standards for intrinsic characteristics of the aircraft, such as tail volume, stability, control authority, etc. This document does not address operational and/or personnel certification regulations that may use the words "pilot" and "flightcrew." Similarly, the scope of the type design is limited to the aircraft itself, its systems, and the applicable airworthiness requirements. Referring to Federal Aviation Administration regulations, for example, this document relates to 14 CFR Part 21 and its associated standards (Parts 23, 25, 27, etc.) as opposed to 14 CFR Part 91 and its associated regulations (Parts 119, 121, 135, etc.).

The interactions between these two streams of regulations and the different types of approvals – airworthiness and operational – can be covered through existing

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mechanisms such as 23.2500(a)(2), for which the showing of compliance with appropriate, quantifiable Means and Methods of Compliance across the stated operational conditions can then be used to support an operational approval.[1]

Command authority, operational approvals, and pilot qualification (including type ratings) are outside the scope of this document.

As such, this document does not redefine “pilot” or “flightcrew.” Rather, this document articulates how remotely and optionally-piloted aircraft designs, as well as uncrewed aircraft designs, comply with the safety intent of the airworthiness regulations. This applies no matter how the terms are defined or whether the terms are even actually required to convey the safety intent of the airworthiness regulations.

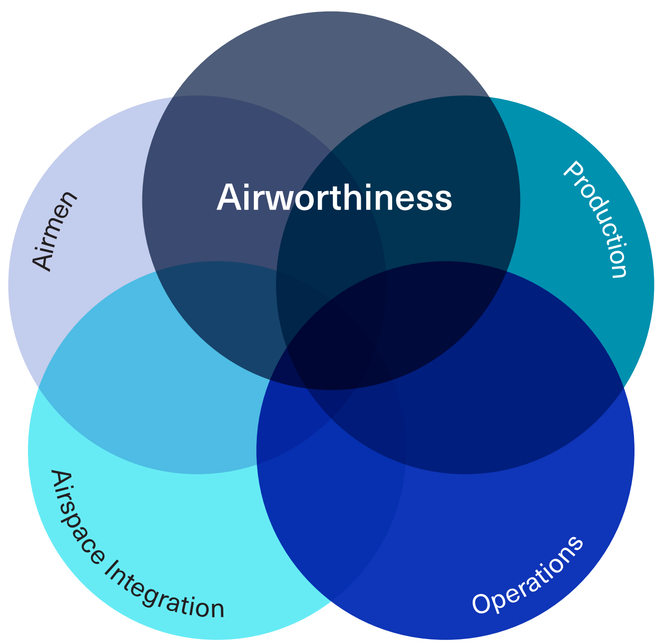

Figure 1: Different types of regulatory oversight have connection points but remain separate processes with their own set of requirements and CAA areas of oversight.

Within the context of airworthiness certification and Part 23 language, it is the purpose of this white paper to show that the safety intent of the regulations is agnostic to the location where an activity is performed, and that this safety intent can be satisfied with a focus on aircraft characteristics and performance, which is agnostic to the allocation of operational activities between human tasks or system functions. It is also possible that without an onboard pilot, certain requirements simply become inapplicable to the aircraft itself.

[1] An example of this approach is presented in ASTM AC377’s prior whitepaper, ASTM TR3-EB. “Regulatory Barriers to Autonomy in Aviation.” 2022.

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Introduction

Airworthiness Certification: Key Concepts and Discussion

PERFORMANCE-BASED RULES AND SAFETY INTENT

Since the 2017 Amendment 64 of Part 23, the top-level rule language has been “performance based.” Furthermore, starting with the European Union Aviation Safety Agency’s (EASA) special condition-vertical take-off and landing (SC-VTOL), new requirements for powered-lift have been drafted in performance-based format. The airworthiness process for Part 23 normal category airplanes and powered-lift flows through three main types of requirements:

Language starts with the safety intent in the “Certification Basis.”
The Certification Basis is written with the intent to convey the safety intent, safety outcome, or “performance” that is desired of the aircraft. This “GOAL” must then be supported by a set of additional, more prescriptive requirements called the “Means of Compliance.”

The Certification Basis is followed by the prescriptive Means of Compliance.
These Means of Compliance are typically derived from industry consensus standards,[2] advisory circulars, issue papers, older rule language, or other pedigreed design standards and requirements. These documents may be referenced directly or used to inform project-specific issue papers. They provide an answer to the question: “What specific criteria must the design meet to ensure that the safety intent ‘GOAL’ is achieved?”

The “Methods of Compliance” are established.
The Methods of Compliance establish the specific methodologies (analysis, design, test, etc.) that will be utilized to show that the Means of Compliance criteria have been met and the Civil Aviation Authority can make a finding of compliance. They provide an answer to the question: “How will it be shown that ‘the what’ has been achieved so as to satisfy the GOAL?”

Figure 2 shows these pieces of the airworthiness requirements package and the questions that connect them.

Certification Basis	► Means of Compliance	► Methods of Compliance
? What outcome (“performance”) is safe?	? What do you do to achieve that outcome?	? How do you show compliance?
– Rule Language – Desired Safety Outcome – “Safety Intent” – Performance Based	– What will achieve the desired safety outcome – e.g., Industry Standards – More prescriptive – More dynamic	– How do you show the what (means) has been achieved? – Practices & Test Methods

Figure 2: Requirements Question Flow.

[2] These standards include those developed and maintained by ASTM Committee F44 for General Aviation Aircraft broadly and F3563-22 by Committee F38 on Unmanned Aircraft Systems to adapt these to uncrewed aircraft.

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When applying a performance-based requirement, the most important consideration is whether the original safety intent of the requirement is being met. It is this safety intent that aims to prevent a given hazard. That hazard was often identified through a history of hard-bought experience; while the means and methods by which that hazard is mitigated may change with new technology, the hazard itself, and its associated safety intent, should not be casually discarded.

The definition of intended functions and the corresponding application of the new performance-based rules defining safety intent, as captured in 23.2500, 23.2505, and 23.2510, allows the use of new, innovative approaches to make aircraft safer without the difficulties of showing equivalence to the prescriptive requirements (now available as Means of Compliance) in previous amendments. This is one example of the way in which the capture of safety intent from previous amendments guiding the current performance-based regulations results in new, safer, and more capable aviation technologies.

Specific prescriptive requirements can be handled in the Means and Methods of Compliance on a project-specific basis while preserving the high-level applicability of the regulation itself. This approach is critical to allowing innovative new approaches to make aircraft safer. Trying to come up with equivalence to prescriptive regulatory requirements for legacy aircraft systems would be difficult and could result in effectively blocking new, safer, and more capable technology.

This trio of intended functions-related regulations provides a functional, certification basis for highly automated and autonomous systems:

- 23.2500 requires a determination that operating envelope and level of safety are in alignment for all intended functions;
- 23.2505 covers the unique considerations of a given installation;
- 23.2510 provides the ability to design and certify an aircraft in a real-world environment that will have to accommodate failures.

Combined, these regulations provide a connection point for Means and Methods of Compliance specific to the systems and functions being certified while clearly stating the overall applicable safety intent. Completing this type design airworthiness certification project sets the stage for a determination of operational suitability and operational approval with a firm understanding of the capabilities of the aircraft in question.

How “Pilot” and “Flightcrew” Are Used in 14 CFR 23 (and in Draft AC 21.17-4)

Remote pilot operations have existed in the military for more than 50 years, but the existing “Normal Category” airworthiness rules were written with the assumption of an onboard pilot and as needed, an onboard flightcrew. This has resulted in the terms “pilot” and “flightcrew” being used not just for requirements rooted in human factors and human-aircraft interaction, but also within requirements that are satisfied through basic aircraft design characteristics.

Every rule within Part 23 was intended to address a hazard. Historically, those hazards were identified on piloted aircraft and as such, the language used to describe them sometimes includes reference to the pilot based on assumptions about the pilot’s role within the aircraft and how the aircraft will be operated, rather than defining fundamental safety intent. As the fundamental consideration for each of the hazards considered by the rule language is not changed by the relocation of the humans responsible for the flight to the ground, or by implementing increasing extents of aircraft autonomy, the core safety intent of these requirements remains valid. The analysis supporting this assertion was completed as part of this work and is summarized in the attached Appendix. One of the motivating factors for the creation of this document is to ensure that these hard-earned requirements can be applied to uncrewed aircraft today, through the appropriate application of their underlying safety intent.

Types of Requirements

The requirements in Part 23 that use the term “pilot” or “flightcrew,” or otherwise imply an interaction with an onboard human, primarily fall into one of the following categories:

- Structural requirements
- Handling qualities/aerodynamics
- General system design
- Repeatability of performance
- Accuracy of stated performance
- Information input/output
- Onboard contingency handling

The safety intent for requirements dealing with **structures and handling qualities/ aerodynamics** can be determined through engineering-first principles, i.e., the linkages must be strong enough to withstand expected control input forces; the authority of the aircraft’s control surfaces must be adequate and their effect predictable; the aircraft must demonstrate apparent stability and be sufficiently controllable; etc. While written in reference to a pilot, these fundamental aircraft characteristics must still be acceptably safe and be demonstrated without anyone onboard hand-flying the aircraft.

How “Pilot” and “Flightcrew” Are Used in 14 CFR 23 (and in Draft AC 21.17-4)

General system design requirements deal with preventing electrical and lightning interference from negatively impacting the performance of pilot and/or flightcrew duties or imposing requirements on autopilot operation during icing conditions (to provide protection from stalling). While the means of compliance may be different for a remotely operated aircraft, the intent and core requirements apply as written and rely upon a definition of flightcrew “duties” that should be determined for operation of the uncrewed aircraft in general.

Requirements that reference a “pilot of average skill” can be categorized as focused on the **repeatability of performance or accuracy of stated performance** of the aircraft. This is effectively a “truth in advertising” requirement, i.e., the procedures in the aircraft flight manual (AFM) or pilot operating handbook (POH) must result in predictable, repeatable aircraft performance. Furthermore, anyone who is appropriately qualified to fly the aircraft must have a reasonable expectation of being able to operate the aircraft within its envelope and have it behave as stated. Requirements that specify that a given flight characteristic must be demonstrated “without exceptional piloting skill” are intended to enable test pilots to recover from outside the nominal flight envelope. This enables traditional flight tests to be performed as safely as is practical.

While traditionally the Means of Compliance for these requirements would involve a test pilot on board the aircraft performing the specified maneuvers and procedures and evaluating the aircraft subjectively, this is not a fundamental requirement of the certification basis. There may be intended function requirements that flow from these requirements, such as the aircraft systems being able to consistently takeoff in a specified distance across the full flight envelope and range of approved operating conditions. The successful execution of these functions would then be covered from a certification basis perspective by §23.2500 and §23.2505. Instead of flight evaluations performed by an onboard pilot, the Means of Compliance for these requirements in an uncrewed aircraft may require a systematic demonstration that the performances are met across the expected operating conditions, where this method requires a demonstration that the required level of safety has been reached for the applied methods. This often requires extensive simulation and corresponding flight tests. The Part 23-64 preamble discusses that for new flight-control systems where the pilot may not have direct pitch, roll, and yaw control, compliance with the flight rules (Subpart B) more explicitly incorporates subpart F as it incorporates systems considerations. Thus, while there may be more flight tests required for an automated aircraft, the existing requirements and the accepted Means of Compliance continue to be applicable.

Information input/output requirements are primarily found in Part 23 Subpart G (Crew Interface). One of the key indications of the safety intent of these requirements is the statement pointing to the “duties” that a crew member must

How “Pilot” and “Flightcrew” Are Used in 14 CFR 23 (and in Draft AC 21.17-4)

perform. In short, any human involved in the operation of the aircraft, regardless of their location, must have the information they need to execute their responsibilities and the ability to affect the aircraft to the extent needed to do so. If there are no onboard “duties” associated with a fully automated function, then these requirements are not applicable to the aircraft. For functions that require remote pilot duties, they may be applied to the control station (CS) or command monitoring unit (CMU) that is employed by the remote pilot. While Part 23 is scoped to include only the aircraft itself, a Type Design Certificate may include operational limitations that require a CS/CMU that meets certain requirements. This is consistent with the original intent of the current CFRs. Though not stated in the preamble, interviews with the original authors of Part 23-64 reveal that 23.2600 was actually written to allow for remote pilots.

Onboard emergency handling (e.g., a fire extinguisher requirement) presents a slightly different consideration than the other types of requirements. Clearly, a fire extinguisher that must be manually operated provides no benefit when onboard an uncrewed and unoccupied aircraft, and whether or not one should be provided where passengers can access it for a remotely operated, passenger-carrying aircraft is a valid question. Fundamentally, the safety intent of these requirements is that the combination of aircraft and human pilot/crew must have a suitably comprehensive set of abilities to mitigate things that may foreseeably go wrong during flight. For an uncrewed aircraft, the Means of Compliance for these requirements will likely shift more functions to onboard systems and sensors and their requirements.

The breakdown of these requirements by type is shown in Figure 3.

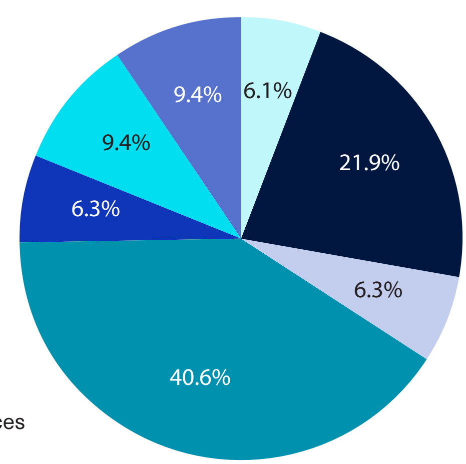

Figure 3: Type of Part 23 requirement that references “pilot” or “flightcrew.”

Please see the Appendix for a table of the 14 CFR Part 23 paragraphs that are relevant to this discussion.

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How “Pilot” and “Flightcrew” Are Used in 14 CFR 23 (and in Draft AC 21.17-4)

Considerations for Retrofit Automation vs. New Aircraft Designs

There are two main ways in which the Part 23 requirements are applied:

1. To a new aircraft that is being built with significant extents of automation and autonomy in mind.
2. As a modification of an existing type design.

For aircraft that incorporate autonomy and/or autonomous systems as a retrofit to an existing aircraft that has a Type Certificate, there is an opportunity to leverage the pre-existing compliance of that aircraft with the Part 23 requirements. The Means of Compliance for a retrofit aircraft may continue to rely on onboard (piloted) flight testing if desired as part of the means and methods.

A clean sheet design that incorporates significant autonomy and automation from the beginning of the design process will rely more heavily on the safety intent of the CFRs and uncrewed demonstration of aircraft characteristics and intended function performance.

Compliance of Uncrewed Aircraft with Requirements that Imply Onboard Crew

While the assumption is that the pilot is onboard, and the aircraft is indeed pervasive in the existing requirements, it is the assertion of this white paper that uncrewed, remotely supervised aircraft can still be compliant with these requirements. The key is the application of the safety-intent concept and the acknowledgement that the reality of uncrewed operation may drive additional requirements in the aircraft design and its intended functions. These additional requirements can be handled through the Means and Methods of Compliance that are applied to a given article and may have implications for both the aircraft and CS/CMU. It is, however, the contributors assertion that existing tools and rules are sufficient, as will be discussed in the following section.

Safety Intent

The concept of safety intent is one that underpins performance-based rules and their application to new and novel technologies. Fundamentally, the safety intent is the desired outcome of the requirement, presented without stipulation as to how that outcome is achieved, but with consideration given to the level of rigor expected to adequately show the safety intent has been met. This provides the maximum flexibility and leaves the pathway to safety-enhancing innovations open. It should be noted that a "performance-based rule" is one that imposes requirements on the ultimate performance or safety outcome to be achieved by the design and is not a rule based on a survey of existing aircraft-performance metrics.

Consider the following example of a performance-based requirement and several (increasingly improbable) potential solutions to satisfy it: "The aircraft design must adequately protect the occupants in the event of an emergency landing." To which a variety of design solutions (answers) may be proposed that do not violate or change the expressed safety intent (the question):

– We are going to use traditional seat belts and harnesses.
– We are going to use multi-directional airbags.
– We are going to use fast-deploying foam to "catch" the occupants.
– We are going to use a trans-dimensional portal. (Presented ironically.)

While the level of effort involved in actually pursuing these different paths to certification – and the Means and Methods of Compliance that would be required for each – varies considerably, the requirement (safety intent) itself is stable and unaffected by the different possible answers or the means by which they would be shown to be adequate. Similarly, when the safety intent of a rule paragraph that assumes an onboard pilot is considered in conjunction with the duties of the remote pilot/flightcrew, appropriate Means and Methods of Compliance can be used that do not require an onboard pilot or flightcrew but that deliver comparable or improved safety outcomes when the system is appropriately designed to replace onboard crew mitigations for unforeseen operational or system states.

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Compliance of Uncrewed Aircraft with Requirements that Imply Onboard Crew

Retaining these requirements and ensuring that their safety intent is met is important, as each existing requirement represents hard-earned experience that contributes to the safety of aviation today. Relocating the pilot and flightcrew does not invalidate the hazard that the original rule language was written to address. The “core” of these requirements – their safety intent – remains valid regardless of the use of “pilot” or “flightcrew.” However, relocating the crew would influence the process by which safety intent is demonstrated and may require reconsideration of assumptions regarding the role of the flightcrew in making that demonstration.

It should be noted the level of rigor associated with demonstrating the safety intent has been met will vary according to the type of aircraft, its intended operation, and the airspace in which it is operating. For example, demonstration of safe operation may rely solely on demonstrated safe-operational flight hours for small unmanned aircraft systems (sUAS) in separate airspace, while the process for documenting the appropriate level of assurance of safe operation for advanced air mobility (AAM) and larger unmanned aircraft systems (UAS) operations in collaborative airspace would require a proper balance of safe flight-test hours, formal design and development assurances, and appropriate operating limitations to meet the safety intent of the applicable regulations.

Connection to Intended Functions

One key piece of the overall requirements and compliance landscape that does warrant additional attention for uncrewed aircraft is that of intended functions. Covered in 14 CFR 23.2500 and 23.2505, intended functions must, to paraphrase, perform their stated purpose over the entire approved operating envelope of the aircraft. The existing airworthiness rules are appropriately silent on what constitutes a complete and correct set of intended functions. What they are and how they are demonstrated satisfactorily across the operating envelope is left to the Means and Methods of Compliance. Compliance with operational rules may necessitate specific actions be performed that are either allocated to human tasks or to intended functions. The adequacy of their performance as shown in the airworthiness process will be evaluated as part of the operational-approval process. While this has led some to assert that there is a certification requirements gap for the intended functions needed for increasingly automated and autonomous uncrewed aircraft, it is the assertion that the operating rules under which such an aircraft would be used provide an adequate level of regulator oversight.

The actions necessary to satisfy the operating rules and perform the aircraft mission do not change between a crewed or uncrewed aircraft. It is only the allocation of these actions to functions performed by a system – or tasks performed by a human – that changes, along with associated assumptions regarding the ability of the system and/or the human to manage necessary functions and respond to unforeseen system states. The specific difficulty is to demonstrate that

Compliance of Uncrewed Aircraft with Requirements that Imply Onboard Crew

the function list (allocated to the aircraft/system) is complete and correct when considering the combinatorics challenge of the operational environment variability and assumptions surrounding the mitigating role of the onboard flightcrew versus remotely located flightcrew. The methods used to address combinatorics in conventional safety analysis have been agreed upon in industry guidelines, but today there are no industry guidelines addressing the combinatorial complexity of the operational environment, which would be necessary to validate the intended function list.

The specifics of this list are highly dependent upon the aircraft, its mission, and its operating environment. The clarity provided by a Functional Breakdown that includes nominal and off-nominal operations published in the first AC377 Technical Report, “Autonomy Design and Operations in Aviation: Terminology and Requirements Framework” is valuable in ensuring a complete list of intended functions, required performance, and operating envelope. However, the development of this product-specific list does not change the safety intent of the rules governing the resulting intended functions.

Means and Methods of Compliance

Means and Methods of Compliance are prescriptive pass/fail requirements and methodologies that are used to answer the question of what, specifically, will be done to show that the safety intent of a certification basis requirement is being met and how that function will be demonstrated. This could be a set of prescriptive load requirements (means) and accompanying test plans (methods) or quantified handling characteristics (means) and automated flight test demonstrations that will collect relevant telemetry and control force data (methods). To support the performance-based Part 23 requirements, a set of industry consensus standards (primarily managed under the committee on general aviation aircraft (F44) has been developed and accepted by Civil Aviation Authorities (CAAs) as “one but not the only” Means of Compliance that can be used to provide the “answers” to the “questions” of the rule language. An applicant may develop and propose additional or alternate Means and Methods of Compliance as needed for CAAs acceptance and application to their specific project.

Each intended function identified as being necessary for compliant operation of the aircraft will have a set of performance requirements (means) and demonstration protocols (methods) associated with it that support the application of 23.2500 and 23.2505. Given the innovative and emerging nature of highly automated and autonomous uncrewed aircraft, these Means and Methods of Compliance will likely be highly project-specific for the near term but, as discussed in the concluding section of this paper, are expected to coalesce into a more durable standards library over time.

Compliance of Uncrewed Aircraft with Requirements that Imply Onboard Crew

One of the key areas of discussion for Means and Methods of Compliance for uncrewed aircraft is related to the flight characteristics and handling qualities of the aircraft. Traditionally, for manned aircraft, these requirements were evaluated subjectively by experienced onboard test pilots with the goal of ensuring that the aircraft could be safely flown by pilots licensed to do so. Depending on the aircraft, consideration was also given to the safety and comfort of the flightcrew and passengers. For uncrewed, unoccupied aircraft, this latter concern is likely moot while the core safety intent of the handling characteristics and aerodynamic performance of the aircraft can be applied; traditional flight testing is not expected to be required as part of the Means and Methods of Compliance though the qualitative assessments achieved during such testing may need to be applied as a quantifiable means or method of compliance. For uncrewed aircraft that carry passengers, a combination of considerations will need to be applied in the Means and Methods of Compliance, with some of the “comfort factors” potentially being qualitatively evaluated by a “test passenger” onboard the aircraft.

Implications for System Safety Analysis

A key part of the compliance approach is the systems safety process. This is comprised of a functional hazard assessment (FHA) and a systems safety analysis (SSA). The FHA is primarily a classification effort, determining the severity of a particular failure condition (i.e., whether the anticipated results are considered (“Minor,” “Major,” “Hazardous,” or “Catastrophic”). This classification yields both qualitative and quantitative safety targets that must be demonstrated for the failure condition identified. For those conditions assigned a quantitative target, the SSA then mathematically demonstrates that the safety targets are met.

Historically, the presence of an onboard pilot has influenced the results of the FHA by allowing for pilot intervention to be used as a mitigation technique to reduce the final classification of a failure. For example, an otherwise Catastrophic failure might be reduced because of the pilot’s ability to intervene.

It has been suggested that one approach to addressing the removal of an onboard pilot is to increase the safety targets corresponding to the various failure conditions. For example, the target likelihood of a Major event may be decreased from 10-3 to 10-4, or that of a Catastrophic event from 10-7 to 10-8. However, this approach belies a lack of understanding of the proper execution of the existing safety processes. There is no need to make a Major event – or even a Catastrophic event – less likely to occur. This approach is arbitrary and introduces imbalances in the safety continuum that is already being applied to the industry. The correct approach is to allow the existing processes to work as they were defined.

Compliance of Uncrewed Aircraft with Requirements that Imply Onboard Crew

For example, consider a failure condition that is classified as Minor due to the availability of pilot mitigation. The corresponding safety target is 10-3. Now, consider that the pilot is removed from the aircraft and with them, the availability of the previous mitigating action. In the most severe case, the failure condition may be classified as Catastrophic once that mitigation is removed, changing the safety target to 10-7. Note that the allowable likelihood of the event is reduced by **four orders of magnitude** by simply following the existing processes, a much more significant (and justified) adjustment than the arbitrary raising of all targets by a single order of magnitude. It is clear that arbitrary adjustments and safety continuum imbalances are unnecessary, as the proper application of the existing process paradigms will already compensate for the removal of pilot mitigations.

Role of the Command Monitoring Unit (CMU)

While there are a variety of associated elements that may be included in the uncrewed aircraft system in question, the majority of them would be outside the scope of this document. However, depending on the functional allocation of duties necessary to operate an uncrewed, increasingly automated or autonomous aircraft, the CMU or CS (also referred to as the ground control station [GCS]) may have a significant role to play in satisfying the safety intent of the existing certification basis requirements. For requirements dealing with human factors and the interaction of the human pilot or flightcrew with the aircraft, the Means and Method of Compliance may fall entirely on the CMU, should that equipment be necessary for the safety of flight of the uncrewed aircraft.

As the extent of automation and autonomy of an uncrewed aircraft, and thus the extent and criticality of the "duties" of the ground-based remote pilot, vary between applications, the extent of oversight that must be applied to ground-based hardware will also vary. This concept of tailored oversight for CMU components was captured in the adopted EASA Opinion 03/2023, which codifies the concept of tailored oversight for CMU components when evaluating uncrewed aircraft systems. As such, while the certification basis language of Subpart G dealing with the equipment needed for "each pilot to perform his or her duties," for example, is adequate, Means and Methods of Compliance applicable to the associated CMU may be necessary as part of the aircraft type certification process. As discussed earlier in the context of Subpart G, Section 2.1, it may or may not be necessary to impose Part 23 requirements on the CMU or include an operational restriction in the type certificate data sheet (TCDS) that references the CMU or other associated elements.

Conclusions and Next Steps

It is the contributors assertion that by applying a safety-intent lens to existing Part 23 regulations, they can be applied – without rulemaking – to a wide variety of uncrewed aircraft, though special conditions may be warranted in some cases. This is important given the pace at which type design certification projects for uncrewed aircraft with ever-increasing extents of automation and autonomy are emerging and maturing. This does not mean, however, that there does not exist ample need for requirements definition. The functional allocation and Means and Methods of Compliance for these aircraft are all critical and represent substantial effort that must be done collaboratively between the Regulator and Applicant.

The development of industry standards that can be used for uncrewed aircraft as acceptable Means and Methods of Compliance with “pilot” and “flightcrew”-centric language would greatly support the industry and relieve resource pressure from the Regulator. While the industry and the enabling technologies are still new enough that they are not ready for a “one size fits all” requirements set, widely agreed-upon safety-intent interpretations of the paragraphs highlighted in the Appendix would be valuable. Additionally, practices and guides for functional allocations and system-safety analyses for uncrewed aircraft that appropriately capture the safety implications of reducing or removing reversionary modes and taking human pilots out of the loop should continue to be developed, applied, and improved.

Another tool that may prove valuable for future work in this area is system theoretic process analysis (STPA) to support the determination of Means and Methods of Compliance that account for overall control structure breakdown rather than just system failure.

Early type certification applications for highly automated and autonomous uncrewed aircraft are being watched with great interest. Lessons learned from these activities should be leveraged by standards-development activities to the greatest practical extent.

Ultimately, further work will be needed to streamline the determination that the certified system functionality of the aircraft (i.e., its intended functions) can satisfy the operational rules. Currently, this is covered within the airworthiness certification demonstration that intended functions perform as stated and a subsequent operational approval process. The development of a requirements set that more explicitly connects the intended functions list to the necessary operational capabilities, and how to implement such a set of requirements within the existing landscape, is left as an exercise for future work.

Appendix

Paragraph	Title	Summary of Safety Intent	UA Applicability Notes	Categorization
23.2000(b)	Applicability and definitions.	Definition of Safety of Flight and Landing; must not rely on "exceptional pilot skill or strength".	N/A definition only	repeatabilty of performance
23.2120(c)	Climb requirements.	Ensure Obstacle clearance.	"Comply through aerodynamic and propulsion system design and performance to ensure capability. Execute flight test that demonstrates required climb."	aerodynamic
23.2130(b)	Landing.	Ensure landing within published values (prevent runway overrun), and ensure ability to transition to missed approach.	"Comply through aerodynamic and propulsion system design and performance to ensure capability. Demonstrate repeatable performance with analysis and flight test across operational limits without reaching limits of the control system. May also inform Means of Compliance (MOC) for automated control system performance."	accuracy of performance
23.2135(a)	Controllability.	Ensure that pilot can consistently keep the aircraft from departing the flight envelope without needing "exceptional pilot skill or strength".	"Comply through aerodynamic design with analysis and flight test to demonstrate repeatable controllability and maneuvering performance across multiple test points of the operational envelope. Demonstrate that the automated control system provides appropriate magnitude control inputs."	accuracy of performance
23.2140(a)	Trim.	"Support pilot in maintaining a consistent flight path; prevent unwanted course/heading changes. Allow externally adjustable tabs and fly-by-wire systems."	"Comply through aerodynamic design with analysis and flight test of automated trim performance. Inclusion of ‘flight control systems’ was intended to acccommodate fly-by-wire systems. May drive additional MOC for Optionally Piloted Aircraft (OPA) control transitions/disengagement."	aerodynamic
23.2140(b)	Trim.	Maintain a consistent flight path; prevent unwanted altitude changes.		aerodynamic
23.2140(c)	Trim.	Ensure trim system does not create a hazard in nominal or anticipated off-nominal situations.		aerodynamic
23.2145(b)	Stability.	Don't let aircraft characteristics make it harder to safely fly the plane.	"Comply through analysis and flight test of stabililty (or apparent stability) performance. Mention of occupants applies to ‘occupied UAs’ to prevent airsickness and injury."	aerodynamic

Appendix

Paragraph	Title	Summary of Safety Intent	UA Applicability Notes	Categorization
23.2150(e)(2)	Stall characteristics, stall characteristics, and spins	Avoid crash due to spin.	"For aircraft with envelope protection (most UAs): Comply with flight test and analysis to show sufficient protection from entering spin regimen. For aircraft without envelope protection: Coply with flight test and analysis to show that the dynamic exposure during spins does not exceed the performance of the automated control system. Regardless of on- or off-board crew, direct compliance is possible."	aerodynamic
23.2160(a)	Vibration, buffeting, and high-speed characteristics.	Prevent flight crew fatigue or distraction (prevent erroneous pilot actions) due to disruptive aircraft flight characteristics.	"Comply through flight test and analysis of UA performance at speeds around V_D. Direct compliance with a remote pilot may be simpler than for on-board pilot."	aerodynamic
23.2225(b)(3)	Component loading conditions	Prevent structural overload.	Already addresses automated flight control systems as written.	information input/output
23.2320(a)(1)	Occupant physical environment	Ensure ability to communicate and coordinate.	"Uncrewed cargo transport: N/A Uncrewed passenger transport: provide intercom capabilities with remote crew Note: means of implementing comms is MOC and not covered in the regulation"	information input/output
23.2320(a)(2)	Occupant physical environment	Ensure propeller does not preclude controlling the aircraft.	"Remote pilot/crew automatically protected from propellers by their location. May drive MOC for protection of onboard flight management or other flight-critical systems and equipment."	structural
23.2320(b)	Occupant physical environment	Prevent bird strike from penetrating the windscreen	May be N/A if no forward windscreen present in aircraft design; otherwise ground test and direct compliance for penetration	structural
23.2325(e)(1)	Fire protection.	Ensure detectability of fire / Prevent fire from spreading unnoticeably.	Comply via ground test of automated fire detection/ suppression system.	on-board emergency handling
23.2325(f)(1)	Fire protection.	"Support overall survivability by: Ensuring ablity to extinguish fire without having to leave the pilot station. Prevent injury or damage possibly incurred if the pilot would have to leave the seat and locate and unstow the fire extinguisher. "	Comply via ground test of automated fire detection/ suppression system.	on-board emergency handling

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Paragraph	Title	Summary of Safety Intent	UA Applicability Notes	Categorization
23.2405(c)	Automatic power or thrust	Ensure ability to maintain consistent flight path.	"Comply via ground and flight test of features preventing inadvertent system activation/deactivation. For OPA configuration, this should be demonstrated for both remote and onboard piloting operations, noting that the control station itself is out of scope of this regulation."	information input/output
23.2425(b)	Powerplant operational characteristics	Ensure ability to recover from a stopped engine.	"Comply via test of the automated system functionality for engine stop and restart in response to pilot command. The scope of the requirement is the aircraft. Thus this imposes a requirement for an input means on board the aircraft that would allow a pilot to command an engine off/on. This does not specificy where that command would be coming from. Whether or not this requierment is in the interest of safety given the cybersecurity concerns of remote powereplant control is a separate question; compliance is still possible. Note: Intended functions, that effect an engine shutdown/restart, are addressed separately from this regulation."	information input/output
23.2440(f)(1)	Powerplant fire protection.	Extend the ability to extinguish a fire beyond the pilot's reach and view.	Direct compliance via test of automated fire detection/ suppression system. By definition, all fire zones on the UA is out of the pilot's reach.	on-board emergency handling
23.2515(b)	Electrical and electronic systems	Ensure operability of essential functions of the aircraft after a lightning strike.	"Comply through ground test and analysis of airborne automation systems components to demonstrate resilience against adverse conditions. Note: Use of ""airplane OR ... flight crew"" allows direct compliance for UA; wording does not force the inclusion of the control station, however applicants may comply with this requirement and include the CS as desired."	information input/output
23.2520(b)	High-intensity Radiated	Ensure operability of essential functions of the aircraft after HIRF exposure.	“Comply through ground test and analysis of airborne automation systems components to demonstrate resilience against adverse conditions. Note: Use of ‘airplane OR ... flight crew’ allows direct compliance for UA; wording does not force the inclusion of the control station, however applicants may comply with this requirement and include the CS as desired."	systems design

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Paragraph	Title	Summary of Safety Intent	UA Applicability Notes	Categorization
23.2530(a)	External and cockpit lighting	Ensure ability to interpret the operating conditions.	"Ground test and flight test to demonstrate direct compliance. Note: 14 CFR 91.205 prescribes operational requirements referring to lightning. This analysis is focused on 14 CFR 23, type design requirements."	systems design
23.2550	Equipment containing high-energy rotors	Prevent cascading damage if high-energy rotors fail.	Direct compliance via demonstration by analysis and/or test as appropriate of the pertinent equipment.	structural
23.2600(a)	Flightcrew interface.	Prevent flight crew fatigue or distraction; arrange items of pilot interaction to support performance of pilot tasks. (Prevent erroneous pilot actions.)	"Direct compliance through ground and flight test related to the intended functions. Note: see the functional breakdown (ASTM AC377 TR1) of the roles and responsibilities of systems and people involved in the safe flight and landing of the aircraft. Need to clearly define ""duties"" of the pilot."	repeatabilty of performance
23.2600(b)	Flightcrew interface.	Ensure flight crew awareness of key information needed to interact with systems and equipment safely and correctly per their assigned duties.	"Direct compliance through ground and flight test related to the intended functions. Note: see the functional breakdown (ASTM AC377 TR1) of the roles and responsibilities of systems and people involved in the safe flight and landing of the aircraft. Need to clearly define ""duties"" of the pilot."	information input/output
23.2600(c)	Flightcrew interface.	Ensure ability to land the aircraft.	Direct compliance through ground and flight test as appropriate to demonstrate capability of remote flight crew and UA to conduct safe landing with one wind shield pane unusalbe (if UA does not rely on external vision, then N/A).	information input/output
23.2605(a)	Installation and operation.	Prevent erroneous flight crew actions due to information confusion.	"Direct compliance is possible via design review/inspection for relevant elements; restricted to UA, not CS. For UA not configured for onboard personnel, this is likely limited to the elements related to power-up or shutdown. For OPA, this is similar to conventional aircraft."	information input/output
23.2605(b)	Installation and operation.	Ensure awareness of necessary information in nominal and off-nominal situations.		information input/output
23.2605(c)	Installation and operation.	Ensure ability to respond if/as needed to unsafe conditions.		information input/output

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Paragraph	Title	Summary of Safety Intent	UA Applicability Notes	Categorization
23.2615(a)	Flight, navigation, and powerplant instruments	Ensure awareness of key information.	"Direct compliance is possible via design review/ inspection for relevant elements; restricted to UA, not CS. For UA not configured for onboard personnel, this is likely limited to the elements related to power-up or shutdown. For OPA, this is similar to conventional aircraft."	information input/output
23.2615(a)(1)	Flight, navigation, and powerplant instruments	Ensure awareness of key information. (Here: Ensure availability of propulsion)		information input/output
23.2615(a)(2)	Flight, navigation, and powerplant instruments	Ensure ability to respond to unsafe conditions.		information input/output

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