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Certification Basis for a Fully Autonomous Uncrewed Passenger Carrying Urban Air Mobility Aircraft

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Abstract

The Urban Air Mobility campaign has set a goal to efficiently transport passengers and cargo in urban areas of operation with autonomous aircraft. This concept of operations will require aircraft to utilize technology that currently does not have clear regulatory requirements. This report contains a comprehensive analysis and creation of a certification basis for a fully autonomous uncrewed passenger carrying rotorcraft for use in Urban Air Mobility certified under Title 14 Code of Federal Regulations Part 27. Part 27 was first analyzed to determine the applicability of current regulations. The fully electric propulsion system and fully autonomous flight control system pose the largest gaps in current airworthiness standards. Part 27 regulations contained 241 directly applicable regulations, 47 regulations were not applicable, primarily due to being “human-centric”, and 34 regulations requiring special conditions. Once these gaps were identified, the extant literature related to autonomous and electric propulsion systems were utilized to propose special conditions and amendments to complete a certification basis for the notional rotorcraft. Amendments were also created to provide suggested regulatory changes to enhance applicability for future autonomous and electric rotorcraft seeking certification under 14 CFR Part 27. The proposed special conditions and amendments aid in the certification, safety, and proliferation of a fully autonomous and electric future.

Keywords: urban air mobility, unmanned aircraft system, autonomous systems, certification

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Statement of the Project

The proliferation of electric multi-rotor Unmanned Aerial Vehicles (UAVs) has ushered in a new era of vertical lift, requiring significant regulatory changes for operators and manufacturers. As electric UAV rotorcraft increase in levels of automation towards full autonomy and passenger carrying capability, certification methods for these aircraft must be clearly established. Current regulatory methods for Type Certification of larger unmanned aircraft fall under Title 14 Code of Federal Regulations (14 CFR) § 21.17(b) for special classes of aircraft that are not specifically covered in Parts 23, 25, 27, 29, 31, and 35. This broad regulatory framework lacks the specificity and flexibility to appropriately set certification requirements and standards for a fully autonomous rotorcraft. Developing regulatory requirements and guidance under 14 CFR Part 27-Airworthiness Standards for Normal Category Rotorcraft that include considerations for a fully autonomous, passenger carrying, fully electric multirotor with the human-out-of-the-loop is necessary for the expansion of Urban Air Mobility (UAM). The current assumption is that UAMs will be a powered-lift design of an airplane type that can transition/convert back-and-forth to a helicopter mode, hence the prevailing position is that they would be certified under Part 23 with special conditions. The study is innovative because it assumes that UAMs will be a pure rotorcraft design, hence would be certified under Part 27 with special conditions.

Purpose Statement

Develop a Type Certificate Compliance Checklist for a fully autonomous uncrewed passenger carrying multirotor aircraft.

Significance of the Study

Type Certification for a fully automated unmanned aircraft is currently regulated under 14 CFR § 21.17(b) as a special class of aircraft requiring adaptation of applicable portions of existing airworthiness requirements and special conditions to accommodate new and novel design features. Determining these requirements requires extensive negotiations with the Federal Aviation Administration through issue papers, special conditions, exemptions, and other proceedings, which increases the cost and time for their certification and subsequent introduction of the aircraft for operations in the National Airspace System. Consequently, there is a need to lay the foundation for a certification basis template for the certification of a fully autonomous, passenger carrying, fully electric multirotor aircraft.

Limitations

Current federal regulations lack defined terminology for autonomy and artificial intelligence, causing inconsistency when attempting to collect relevant research regarding fully autonomous unmanned aircraft. A Standards Development Organization (SDO) recognized by the FAA, the Radio Technical Commission for Aeronautics (RTCA), does not publicly provide their certification standards for unmanned aircraft hence were unavailable for reference while conducting research.

Delimitations

Research will be conducted with focus on a specific uncrewed aircraft. The notional aircraft is an uncrewed, electric, 16-rotor UAM aircraft that is capable of carrying two passengers in a non-pressurized cabin. The research is also delimited by not including the certification of the algorithms that make up the autonomous decision-making or artificial intelligence (AI) of the notional aircraft. However, certification of the AI would be required for complete certification of the aircraft.

Assumptions

Title 14 CFR's lack of definitions for autonomy, artificial intelligence, and hierarchy of levels of automation require assumptions that will lay the foundation of the research. Autonomy will be defined as, "The ability of an intelligent system to independently compose and select among different courses of action to accomplish goals based on its knowledge and understanding of the world, itself, and the situation" (Shattuck, 2015, slide 6). Artificial Intelligence (AI) will be defined as, "the ability of a system to act appropriately in an uncertain environment, where an appropriate action is that which increases the probability of success, and success is the achievement of behavioral sub- goals that support the system's ultimate goal" (Shattuck, 2015, slide 6). The Department of Defense's Levels of Autonomy includes four levels of automation. The fourth level, Fully Autonomous, is defined as, "The system receives goals from humans and translates them into tasks to be performed without human interaction. A human could still enter the loop in an emergency or change the goals, although in practice there may be considerable time delays before human interaction occurs" (Cook et al., 2019, p. 16). This four-level hierarchy provides a framework to define levels of autonomy and assure that reviewed literature is applicable for the notional fully autonomous aircraft.

Research Question

What are Type Certificate Compliance Checklist requirements for a fully autonomous uncrewed passenger carrying multirotor aircraft be developed under Title 14 of the Code of Federal Regulations (14 CFR) Part 27?

Literature Review

Regulations

Title 14 CFR § 21.17 is the established method for present day type certification of Unmanned Aircraft Systems. The special class category of aircraft is legislation that allows the FAA to Type Certify an aircraft that is not already completely regulated under 14 CFR Parts 23, 25, 27, 29, 31, 33, or 35 (Designation of Applicable Regulations, 2022). This existing framework is what the FAA is utilizing until more robust regulation is created and adopted. In September of 2020, the FAA released a notice of policy for the type certification of unmanned aircraft as a special class of aircraft. Certain UAS may exceed current airworthiness standards and UAS that normally would apply for a standard airworthiness certificate now must reference 14 CFR § 21.17 for type certification (FAA, 2020). Definitions for unmanned aircraft systems were established by the FAA and terms such as Unmanned Aircraft (UA), Unmanned Aircraft Systems (UAS), Small Unmanned Aircraft, Direct Control, and many others will aid in determining required and acceptable methods of compliance for the fully autonomous unmanned aircraft (FAA, 2018).

Guidance

The FAA anticipates large economic benefits when passenger-carrying Urban Air Mobility (UAM) aircraft are integrated into the National Airspace System. Efficient and effective certification procedures will be required to take advantage of this potential benefit. The House of Representatives Report No. 115-750 identifies the lack of regulation and certification procedures that these large aircraft require. Integration of UAM aircraft into the airspace system and subsequent economic impacts are outside the scope of the study but the recommendations section of this House of Representatives Report provides insight into the FAA's regulatory approach (circa 2019) for large, unmanned aircraft. The report references the need for performance-based standards instead of prescriptive design standards to optimize certification procedures. Performance-based requirements allow for original technologies to be certified as compliance is shown through the capabilities of the design vice constraining the design to a certain configuration, type, dimensions, or other specific bounding condition. This report is concise and will aid greatly while determining methods of compliance when creating the Type Certificate Compliance Checklist (House of Representatives Report No. 115-750, 2019).

Other design considerations such as human factors are required for a complete certification basis. Human factors for a fully autonomous UAM aircraft would primarily concern the ground control station interface that controls the aircraft. FAA Advisory Circular (AC) No. 00-74, Avionics Human Factors Considerations for Design and Evaluation, identifies two reports that offer guidance related to human factors. The first referenced report, RTCA DO-372, addresses human factors and pilot interface concerns related to avionics. Recommended practices are developed and explained within this document and are endorsed by FAA AC 00-74. Six primary elements are identified for designers and evaluators to consider during the evaluation process. These elements include Display and Hardware Characteristics, Information Presentation, Alerting, Annunciations, and System Status Indications, Controls, Flight Deck Arrangement, and Automatic Flight Control and Flight Guidance Systems. The next report, DOT/FAA/TC-16/56, is an all-inclusive reference for flight deck displays and control regulations and guidance. Several FAA Aircraft Certification projects have identified recurring topics related to human factors that continually cause issues during certification. The FAA released this report to provide guidance to alleviate future certification issues related to these topics. It is stated within FAA AC 00-74 that the guidance contained within this report is not a MOC. The report also states that guidance contained within these reports are developed for crewed aircraft but share commonality with unmanned systems, specifically UAS ground control stations. FAA AC 00-74 can be leveraged in the development of the UAM aircraft's certification basis as MOCs for the ground control station can be developed through the provided resources within this report (FAA, 2019).

Additional guidance material such as FAA Advisory Circular (AC) 27-1B provides guidance for certification procedures and aircraft airworthiness standards for normal category rotorcraft. Chapter 1 of AC 27-1B includes specific guidance for certification procedures for products and parts. While 14 CFR § 21 - Certification Procedures for Products and Parts regulates certification, the additional guidance of AC 27-1B includes the FAA's stance on certification of unique designs under Part 27. The FAA acknowledges that regulations will lag behind state-of-the-art technology due to the time required to create effective regulations. Special conditions provide the ability for novel designs to be type certified; however, the FAA states that early consultation of their respective FAA authority may enlighten applicants to the applicability of already existing regulations (FAA, 2018). The notional UAM aircraft lacks any onboard crew which will complicate certification as full autonomy is not currently explicitly addressed in FAA regulations. The Department of Transportation (DOT) Inspector General in March of 2022 provided clarity that the FAA understands that UAM aircraft intend to be fully autonomous and will not have crew members on board (Smith, 2022).

Special Airworthiness criteria is currently utilized to certify Unmanned Aircraft Systems (UAS) under 14 CFR § 21.17(b) - Special Classes of Aircraft. Durability and reliability (D&R)

standards set the framework for the FAA to certify different UAS under Part 21.17(b). The D&R process includes different elements that applicants must develop such as a concept of operations (CONOPS), design criteria, analytical analysis, and experimental demonstrations (flight test). For example, the Yamaha Fazer R, unmanned gasoline powered rotorcraft, was certified under 14 CFR § 21.17(b) through performance-based D&R criteria. One performance-based criteria associated with Yamaha Fazer R, states that external sources causing interference must be minimized (FAA, 2018). Induced failures such as Global Positioning System (GPS) failure or inertial navigation system (INS) degradation could be executed to demonstrate durability and reliability. Assurance that the aircraft will operate as intended is established through the D&R process and allows for applicants with even novel designs to demonstrate that their aircraft are safe and predictable.

Additionally, Amazon Logistics Inc. certified their MK27 unmanned Vertical Takeoff and Landing (VTOL) aircraft under 14 CFR § 21.17(b). The certification established several durability and reliability (D&R) standards for the entire operational envelope for the aircraft. The proposed D&R criteria include flight test evaluation of the aircraft where zero fail tolerance is required. Successful completion of D&R testing and any subsequent 14 CFR § 21.17(b) certification will establish the ability for the aircraft to operate over predetermined areas of maximum population density. Testing failures would include, loss of control, loss of flight, loss of containment and emergency landing outside of the aircraft's launch and recovery area. This D&R testing demonstrates the depth of reliability that is required for the notional UAM aircraft to operate over heavily populated areas. Additionally, this certification includes contingency planning for communication and Command and Control (C2) link degradation, high intensity radiated field (HIRF), lightning, and adverse weather requirements as well as cyber security requirements (FAA, 2020, p. 2-5).

The notional fully autonomous passenger carrying UAM aircraft utilizes lithium battery technology and AC 20-184 provides airworthiness criteria that will aid in creating a comprehensive certification basis (FAA, 2015). Installed rechargeable lithium batteries currently are a regulatory gap in both Part 27 and Part 33 regulation and will require special conditions or equivalent levels of safety (ELOS) for the notional rotorcraft to be certified under Part 27. AC 20-184, while comprehensive, is not a regulation and can only be utilized to determine methods of compliance for the notional rotorcraft's certification basis. AC 20-184 contains guidance for installation of Lithium battery systems and Lithium battery fire hazard considerations which could be used as an ELOS in the certification basis. The scope of this AC includes aircraft seeking Type Certificate certification under 14 CFR Part 27. AC 20-184 includes definitions as well as maintenance and instructions for continued airworthiness. Lithium battery safety will be paramount as the novel technology is integrated into the certification basis. AC 20-184 includes possible failure modes for lithium batteries and includes: Overcharging, Over-discharging, Flammability, Internal Defects, and Extreme Temperature (FAA, 2015). These failure modes will be leveraged to provide methods of compliance for the propulsion and fuel system airworthiness criteria.

Industry Standards

Defining terms such as automation and artificial intelligence creates a foundation for regulation. Entities such as the United States Department of Defense (DoD) and the National Highway Traffic Safety Administration (NHTSA) have developed a hierarchy of automation.

The NHTSA developed an automobile based, six levels of autonomy that starts with Level 0: Momentary Driver Assistance and peaks at Level 5: Full Automation (NHTSA, n.d.). The DoD has adopted a four-level hierarchy of automation that begins with Level 1: Human Operated. The top level of DoD automation is Fully Autonomous, defined as: “Systems receive goals from humans and translate these goals to tasks to be performed without human interaction” (Cook et al., 2019, p. 16). This describes the level of autonomy that the proposed Urban Air Mobility (UAM) aircraft operates.

Leveraging existing definitions and concepts will reduce ambiguity while creating the certification basis for the notional aircraft. Stability and control for the fully autonomous passenger carrying rotorcraft will be completely controlled by the onboard flight control computer. This will lead to certification, regulatory and definition gaps as there currently are no Part 27 regulations that directly regulate the stability and control capabilities of a fully autonomous flight control computer for rotary wing aircraft. “Controllability may be defined as the capability of the airplane to perform, at the pilot's wish, any maneuvering required in total mission accomplishment. The characteristics of the airplane should be such that these maneuvers can be performed precisely and simply with a minimum of pilot effort” (USNTPS, 2019, p. 27). This definition can be easily utilized to create a comprehensive definition for the goal of a rotary wing autonomous flight control system. An adapted version of this definition would state,” Controllability may be defined as the capability of the airplane to perform, via autonomous flight control logic, any maneuvering required in total mission accomplishment. The characteristics of the airplane should be such that these maneuvers can be performed precisely and simply without exceeding computational limitations of the onboard flight control computer.”

The proliferation of autonomous automobiles was the impetus for the Society of Automotive Engineers (SAE) to develop their own automation hierarchy. However, levels of autonomy have not been formally defined by the FAA or any other civil aviation authority (CAA). The SAE developed their six-level hierarchy of automation based upon the purpose of the automated driving feature. Level 0: No Driving Automation, excludes any type of driving automation. Level 5: Full Driving Automation, is the unconditional execution of driving tasks by the automated system. Level 5 automation can be applied and modified to develop baseline definitions for the development of the certification basis for the UAM aircraft (SAE International, 2021). A modified definition of SAE Level 5 automation that defines the automation of the UAM aircraft is, "the consistent, safe, and un-intervened execution of flight tasks by the onboard flight automation system."

Terminology/Definitions

The ASTM (2022) Technical Report (TR-3), Regulatory Barriers to Autonomy in Aviation, addresses the process of integrating autonomy into current regulations and provides a clear methodology for determining what barriers currently exist and how to overcome them. It breaks down 14 CFR Part 91-General Operating and Flight Rules regulatory requirements and notes that 85 percent of Part 91 presents no barriers after analyzing 3,171 regulatory line items. Only four percent of Part 91 is noted to present large barriers to regulatory change which would include terms such as Pilot in Command (PIC) and opens the debate to whether automation or artificial intelligence can fill the role of PIC. Terminology such as this would require change in a new certification basis due to the lack of onboard crew on the proposed aircraft. While operating regulations (14 CFR Part 91) are out of the scope of the proposed research, the report also analyzes 14 CFR § 1.1-General Definitions which is applicable to the regulations in a certification basis (Cook & Dietrich, 2022).

Certification Basis

The proposed certification basis for the notional UAM aircraft will be under 14 CFR Part 27, Normal Category Rotorcraft with special conditions. When adequate safety standards for a particular design require regulations that exceed current standards, the design may still be certified under 14 CFR § 11.19-Special Conditions (What is a special condition, 1996). An accurate certification basis requires appropriate regulations to be followed. Previously, the FAA considered whether UAM aircraft will be certified under 14 CFR § 21.17(b) or 14 CFR Part 23 with special conditions (Smith, 2022). The Joby Aero, Inc. JAS4-1 is an electric vertical takeoff and land (VTOL) aircraft that carries four passengers with an onboard pilot and conducts a similar mission to the notional rotorcraft. The FAA released certification standards for the JAS4-1 under 14 CFR § 21.17(b), referencing requirements in 14 CFR Parts 23, 25, 27, 29, 31, 33, and 35 when appropriate (FAA, 2022, p. 2). Specific portions of 14 CFR must be identified for their applicability to the notional UAM aircraft. This category's airworthiness standards must be included at the appropriate amendment level for a complete certification basis. The date of the application will establish the amendment level of the appropriate regulations. Other aircraft requirements such as aircraft noise, may be required as well for Type Certification. The novelty of the proposed design may require changes, amendments or additions and must be included while developing the certification basis (Joslin, 2017). Once the applicable portions of 14 CFR are identified, determining how compliance will be shown or the Methods of Compliance (MOC) is the next step in developing the certification basis. MOC can come in various forms from analytical and experimental analysis to inspections or statements of similarity. Equivalent levels of safety (ELOS) may be developed to show compliance with an airworthiness standard that the design cannot directly show compliance. FAA Issue Papers (IP) are utilized to develop ELOS. IPs can also be issued for novel designs that may have unique MOC and require coordination with the FAA directorate or policy office (FAA, 2014). Once applicable regulations and MOC are determined, the FAA and applicant meet and agree upon the finalized certification basis (FAA, 2018).

Software Certification

The notional UAM is uncrewed and fully automated, leaving the aircraft's real time decision making completely dependent upon the onboard algorithms. Certification of the algorithms behind the software, while critical to a complete certification basis, is beyond the scope of the report. However, assuring the appropriate certification of the software is required. In Certification and Software Verification Considerations for Autonomous Unmanned Aircraft the article compares the Radio Technical Commission for Aeronautics (RTCA) DO-178C ("Software Considerations in Airborne Systems and Equipment Certification") and the developed Autonomous Rotorcraft Testbed for Intelligent Systems (ARTIS) certification methods to identify gaps and incompatibilities with current software certification standards (Torens, 2014).

Formal Methods for the Certification of Autonomous Unmanned Aircraft Systems, published by the University of Liverpool in England, discusses the organization of formal methods to certify an autonomous aircraft. The report focuses on the certification of high-level decision making for an autonomous vehicle and presents a methodology on how to structure unmanned aircraft certification. There are no references to any FAA certification requirements but the overall chronological approach to certification will be useful in creating a certification basis (Webster, 2011).

Certification of the autonomous flight control logic is one of the most safety critical systems that must meet airworthiness standards. Currently, autonomy is not directly addressed in FAA regulations. Software certification methods follow airworthiness standards such as RTCA DO-178C where the significance of the failure determines the rigor of certification. A fully autonomous system controls the entire aircraft via software, requiring the highest level of certification standards. Level A software certification is the more stringent certification level and is applied to flight critical software (Rivera et al., 2020). Run time assurance is a technique that is leveraged for a nondeterministic computational system to operate in a degraded state. Essentially a simpler, more deterministic safety system monitors the outputs of the highly complex nondeterministic system. If degradation is sensed, the simpler system takes control and the system utilizes the simpler system's, less capable but still safe, outputs (ASTM, 2021). Current certification techniques for non-deterministic autonomous systems include *freezing* a variant of the software and testing it to industry standards. Even once certification standards are met, the re-certification of the software is required as it continually learns and iterates. This differentiates the ability to update automobile autonomy versus aircraft autonomy as car software can constantly learn and iterate real time while aircraft software collects data and aircraft software developers utilize this data to create and certify updates. Future endeavors that include improving nondeterministic software certification are currently underway (Rivera et al., 2020).

Hardware Certification

Certifying the all-electric propulsion system on board the aircraft will require separate certification procedures from traditional internal combustion engine requirements. Performance and Stability and Control (Flying/Handling Qualities) of the UAM aircraft are influenced by the operation of the propulsion system and requires robust certification to assure safety of flight. The report, *Initial Airworthiness Requirements for Aircraft Electric Propulsion*, identifies regulatory shortcomings such as technological limitations and the lack of certification history of electric aircraft and electric engines. One technological limitation that is discussed includes the required energy densities for the propulsion of large aircraft. It is estimated that 500-1500 W-h/kg of energy is required for large commercial aircraft while current battery technology is only capable of 150-250 W-h/kg. This inherently introduces regulatory limitations as the electric propulsion system may be unable to perform at the same level as an internal combustion engine. The report suggests that reliability systems engineering, applied correctly, can introduce certification processes that will assure safety of flight and effective certification of electric propulsion systems (Yildiz, 2022).

Electric Propulsion

The notional UAM aircraft is propelled by sixteen brushless-outrunner electric engines. The certification basis for the UAM aircraft will require compliance with applicable regulations from 14 CFR Part 33-Airworthiness Standards: Aircraft Engines. 14 CFR Part 33, which was developed with internal combustion engines in mind as the primary propulsion technology of aviation is based on fossil fuels. Failure modes of aircraft engines are tied directly with the type of technology that they utilize. The technological differences between electric and internal combustion engines are non-trivial and substantial gaps in safety standards have become apparent in Part 33. Particularly, 14 CFR Part 33 subparts B through G are only applicable to internal combustion aircraft engines. However, applicable regulations from Part 33 are still relevant such as hazard prevention including fire, loss of thrust and high-energy debris. Proportionate special conditions will require development for equivalent safety levels to certify an electric propulsion system (FAA, 2021).

The notional rotorcraft's electric powerplant adds an additional level of complexity to the novel certification basis. The Joby Aero Inc., JAS4-1 Powered Lift aircraft is an electrically powered VTOL hybrid aircraft that plans to carry four passengers and a pilot. The JAS4-1has similar specifications and performance capabilities utilizing the same type of fully electric propulsion as the notional rotorcraft. The FAA has established design airworthiness standards for the JAS4-1 for type certification under § 21.17(b). The JAS4-1 presents several unique design features including the combination of wing-borne and rotary-borne flight due to the VTOL configuration. The JAS4-1 design is a powered-lift aircraft which utilizes engine-driven lift devices or engine thrust for lift during vertical flight regimes and non-rotating airfoil(s) for lift during horizontal flight. This presents certification novelties due to having to apply Part 23-Normal Category Aircraft Airworthiness Standards and Part 27. The electric propulsion system utilized by the JAS4-1 is a distributed electric propulsion system that can provide thrust for completely vertical takeoff and landing (FAA, 2022, p. 2). The FAA comments on the certification of the powerplant for the JAS4-1 include considerations for a multi-engine isolation system, control of distributed propulsion and crashworthiness related to vertical takeoff and landing. The FAA's proposed airworthiness criteria for JAS4-1 covers all facets of the type certification of the aircraft. Performance-based airworthiness criteria is proposed and includes several criteria applicable to the notional rotorcraft such as, performance data for hovering ceilings that include a wide array of ambient conditions in and out of ground affect. Additionally, the aircraft must be able to execute an emergency landing after a critical loss of thrust. Means other than autorotation are acceptable (FAA, 2022, p. 5). Energy systems are also included in the proposed airworthiness criteria and include discussion of including energy storage isolation systems and acceptable loads that must be withstood (FAA, 2022, p.9). Overall, this FAA special condition for airworthiness standards provides guidance to possible methods of compliance for the electric propulsion system utilized by the notional rotorcraft.

The magniX USA 14 CFR Part 33 special condition certification provides electric powerplant-centric certification standards that can be applied to the notional rotorcraft. This final special condition release for magniX USA includes the FAA's special condition criteria for the magniX USA, magni350 and magni650 electric engines for use in aircraft. In this report, the FAA acknowledges that significant limitations exist in Part 33 when applicants with electric powerplants seek airworthiness certification. Part 33 regulations are established with the baseline assumption that fossil-fuel technology is utilized. This is not the case for fully electric powerplants. Certification standards for cooling, mounting, structure, engine control systems, instructions for continued airworthiness as well as other requirements are determined for the magni350 and magni650 fully electric powerplants (FAA, 2021, p. 6-23). The precedent set by this certification is directly applicable to the notional rotorcraft's fully electric powerplant.

The European Union Aviation Safety Agency (EASA) released a finalized special condition, SC E-19, in 2021 to set forth airworthiness certification standards for electric / hybrid propulsion systems (EHPS). The scope of SC E-19 included any EHPS that produces lift, thrust, or power for manned or unmanned aircraft. SC E-19 provides guidance for the notional rotorcraft's propulsion system certification. SC E-19 provides methods of compliance for every category of the electric propulsion system with performance-based airworthiness criteria. For example, EHPS.380 Propulsion battery, includes the certification standards for an electric powerplant's battery system. EHPS.380 states clearly but ambiguously that any EHPS battery system and battery management system must be designed and constructed to provide sufficient power for the electric powerplant to meet requisite powerplant safety and performance criteria. While SC E-19 will aid in filling regulatory gaps in Part 33 and Part 27, it is not as detailed or comprehensive as established regulations for powerplants such as 14 CFR Part 33 (EASA, 2021). Combining applicable parts of Part 33, Part 27 and special conditions established in SC E-19, as well as special conditions from various FAA § 21.17(b) certifications, a robust certification basis for the fully electric powerplant can be established.

UAS Command, Control, and Communication (C3) Standards

The notional UAM aircraft is fully autonomous and uncrewed but will be required to communicate to ground stations, air traffic control, and other aircraft during operation. NASA notes in their *UAM Vision Concept of Operations*, that the current communication spectrums that are aviation-protected will be exceeded due to the robust communication and networking that will be required for fully autonomous UAM operations. Denoted in the Yamaha Fazer R special airworthiness certification, the FAA's standards for UAS communication states, "1. The applicant must define the type, methods, and operational limits of communication, including the mitigation of any hazard created by any loss of communication between the flight crew and between the flight crew and the UAS. 2. A means must be provided to allow for all communication necessary to safely operate the UA" (FAA, 2018, p. 4). Therefore, standards for command, control and communication will be based upon several different functionalities. The first functionality is communication through three different communication paths: aircraft-to-aircraft, aircraft-to-ground, and ground-to-ground. All three of these paths will be utilized throughout the flight envelope to include ground-based operations. Communication will be required during beyond visual line of sight (BVLOS) operations and certification for contingent operations such as aircraft to ground communication casualties must be considered. Other functionalities such as navigation, electromagnetic interference (EMI) protection and cybersecurity are all considerations that must be applied to the certification basis (Deloitte Consulting LLP., 2021).

The 3DRobotics Government Services H520-G rotorcraft (H520-G) was certified under 14 CFR Part 21-Special Class Airworthiness Criteria and highlighted several regulatory gaps that included ground control of autonomous aircraft. Currently ground stations and command and control stations do not specify FAA design certification criteria. The main utility of the ground station is to provide real time telemetry for a ground operator to assess inflight failures and safety of flight. In the H520-G's Part 21 certification, the ground control station was required to have all pilot instruments displayed at the ground station to mitigate the risk of loss of control of the aircraft (FAA, 2022, p. 2). Since the notional aircraft is completely pilotless and includes "human-out-of-the-loop" decision making, a ground station for in-flight operations would be trivial, providing ground crew only descriptive flight updates without the ability to control the aircraft.

Flight Path Management/Collision Avoidance

Autonomous decision making will be a novel portion of UAM certification and integration into the National Airspace System. Collision Avoidance (CA) and Flight Path Management (FPM) is a key functionality of a fully autonomous aircraft's flight control system. A robust FPM system will be required to assure safety of flight and comprehensive certification of the notional UAM aircraft. Hazard deconfliction typically is managed by the Pilot in Command (PIC) onboard a manned aircraft. The PIC and crew onboard the aircraft work with onboard systems and ground-based controllers and systems to manage any unplanned/unpredictable hazards, object, or weather avoidance. The notional UAM aircraft and a manned aircraft share the ability to have onboard sensors and communication with a ground station but do not share the ability to have a human pilot make timely flight path corrections to assure deconfliction. The notional UAM aircraft's detect-and-avoid decision making will make real time flight path corrections that avoid intruder aircraft. Certification of the actual programming is beyond the scope of this report but requires consideration for certification basis development. Design guidelines for FPM systems are detailed within this report from the AIAA and include utilizing a four-dimensional trajectory framework for the aircraft to operate. Considerations for time, along with longitude, latitude and altitude allow for more accurate strategic planning and decision-making for the aircraft's flight path. This boosts safety as the aircraft's decision making includes consideration for time spent traveling and usable energy remaining. A highly adaptable FPM system allows for designers to focus on certification and optimization of the airframe and propulsion (Karr et al., 2021).

AC 120-123 provides FAA guidance regarding Flightpath management and autopilot integration in aircraft and for managing the degradation of automated systems onboard an aircraft equipped with a FPM system. This guidance may be adapted to the certification basis for the notional rotorcraft as the onboard flight control system includes a fully autonomous FPM system that must fulfill the tasks of an onboard pilot. Recognition and response to degraded states of autonomy and avoidance of in-flight hazards traditionally were executed by an onboard pilot. Training and familiarity with the onboard automation mitigated the risks of degraded pilot-relief modes (FAA, 2022, p. 24). The notional rotorcraft's automated system will be required to handle these situations with an equivalent level of safety of a certified pilot.

UAM Certification, Urban Operations and Passenger Carrying Considerations

In the AIAA article, *Paths to Autonomous Vehicle Operations for Urban Air Mobility*, a comprehensive overview of the concept of operations, applicable hazards, and a path to incorporating a fully pilotless UAM aircraft into the National Airspace System is reviewed. Operation of a pilotless, passenger carrying aircraft over a densely populated area will require extremely thorough certification standards to ensure passenger and non-passenger safety. Due to the proximity of people, property, and the lack of onboard crew, required safety levels for the UAM aircraft will be extremely high. The article outlines two paths to safely introduce operation of UAM aircraft. The first path is the piloted aircraft path where a pilot is present and has the ability to control the aircraft to prevent an undesirable aircraft state. The second path is the pilotless aircraft path and does not involve a human pilot. The second path is in congruence with the notional UAM aircraft and the proposed path to operational certification provides a general overview that will provide guidance during the creation of the certification basis. Amended or new regulations may need to be proposed for certification of the UAM and the article outlines necessary developments for the integration of passenger carrying, fully autonomous UAM. Necessary improvements include communication, propulsion and airframe technology, policy for safety critical hardware and communication regulations (Mather et al., 2019). The created certification basis would provide necessary development to streamline design and certification of UAM aircraft and aid in the operational integration of these aircraft.

The notional rotorcraft's CONOPS includes carrying passengers in congested and urban areas of operation. Traffic avoidance and terrain awareness must be included in the flight control logic to assure safe flight path deconfliction. The notional rotorcraft's CONOPS would require Part 135 operation. The FAA has already allowed for package delivery by drone under Part 135 operation (FAA, 2022). These missions include similar beyond visual line of sight (BVLOS) operations as well as flight above populated areas. Currently, 14 CFR § 135.154 requires turbine powered airplanes carrying six or more passengers manufactured after March 29, 2002 to include a terrain awareness warning system (TAWS) (Terrain awareness and warning system, 2000). A Traffic Alert and Collision Avoidance System (TCAS) is required under 14 CFR § 135.180 for aircraft carrying ten or more passengers (Traffic Alert and Collision Avoidance System, 1994). Hence both TAWS and TCAS would be required to be certified as part of the design of the notional aircraft.

Summary

Current literature related to the development of the certification basis for the notional rotorcraft is readily accessible through government, academic, and industry research reports along with proposed/final special conditions by the FAA and EASA for aircraft of similar designs. Initially, regulations are reviewed to establish a baseline for the certification basis. FAA

ACs, TSOs, exemptions, equivalent levels of safety, special conditions and special class airworthiness standards provide guidance for FAA perspective on the airworthiness certification for the novel electric and fully autonomous systems included in the notional rotorcraft. Additional industry standards such as the levels of autonomy adopted by the NHTSA provide clarity to the definition of fully autonomous. Terminology in current Federal Aviation Regulations (FARs) does not address fully autonomous rotorcraft. However, ASTM technical reports (TR) have provided insight on regulatory changes that will be required for regulation to be adapted to autonomous aircraft. The creation of the actual certification basis will be conducted under 14 CFR Part 27-Airworthiness Standards for Normal Category Rotorcraft. The certification basis will be created utilizing applicable regulations as well as leveraging alternate methods of compliance such as ELOS and SCs. Software and hardware certification procedures are non-trivial with the notional rotorcraft due to the novel electric propulsion system and full autonomy. ASTM International standards utilizing run time assurance (RTA) design techniques can be leveraged for software certification. Additional considerations for electric engine components will require alternate methods of compliance due to insufficient regulations and guidance under 14 CFR Part 33. The EASA SC-19 provides electric / hybrid propulsion system guidance as well as the magniX USA special condition certification can be leveraged in the powerplant special condition requests throughout the certification basis. The special class airworthiness certification of the Yamaha Fazer R and 3DRobotics H520-G shows the FAA required standards for communication links for autonomous aircraft. While the notional rotorcraft does not require a remote pilot, constant connection to a ground station and air traffic control is required for safety of flight. Collision avoidance and flight path management will be conducted autonomously by the notional rotorcraft. Typically, this is a pilot function but will now be done by the onboard flight control computer. Guidance for autonomous FPM/GCA from the AIAA and AC 120-123 will be leveraged throughout the certification basis to assure the onboard autonomy meets requisite FAA safety standards. The notional rotorcraft and subsequent certification basis is based upon the UAM campaign to efficiently transport people and cargo in urban areas. The AIAA's considerations for occupant and bystander safety will be paramount in creation of the certification basis. Additionally, the AIAA highlights the need for improved communication, propulsion, structure and safety critical policies. These considerations will be applied to the Part 27 certification basis of the notional rotorcraft to assure performance-based airworthiness standards comprehensively certify the aircraft as well as provide broad regulatory framework for future projects.

Method

Research Design

Research in support of a fully autonomous rotorcraft will be accomplished through reviewing existing regulation and literature via library sources and electronic scholarly sources. Finding archival data and information from scholarly articles, regulatory and advisory bodies will be utilized to show compliance with current Federal Aviation Regulations (FARs). These documents are found in Embry-Riddle Aeronautical University's Hunt Library, electronic Code of Federal Regulations (eCFR.gov), National Aeronautics and Space Administration (NASA) Technical Reports Server (https://ntrs.nasa.gov/), FAA Dynamic Regulatory System (DRS.FAA.GOV), SAE Mobilus and ASTM Compass research databases, and online published scholarly articles by various engineering journals and educational institutions. The lack of experimentation and surveying with human participants will preclude the requirement of the Institutional Review Board. The certification requirements and guidance for autonomous automobiles could be adapted to aviation. Reviewing documents such as Federal Motor Vehicle Safety Standards (FMVSS) for Automated Vehicles provides a useful framework that can be altered and applied to fully autonomous aviation.

Data and Information Collection

The American Society for Testing and Materials (ASTM) Compass Database will provide ASTM standards for determining Methods of Compliance (MOC) for the proposed UAM aircraft. Several of the ASTM standards such as F3663-22, *Standard Specification for Design and Construction of Large Fixed Wing Unmanned Aircraft Systems*, will provide a reference for determining methods of compliance to create a certification basis for the UAM aircraft. The FAA's online Dynamic Regulatory System (DRS.FAA.GOV) will be utilized to create a tabular regulatory basis for the proposed 14 CFR Part 27 Type Certification Compliance Checklist. Once the most current regulatory basis for 14 CFR Part 27 is downloaded and tabulated, each column will be evaluated and filled in to reflect the appropriate MOCs, Applicable References/Guidance and any additional remarks that are required. DRS.FAA.GOV will also be utilized to research FAA Orders, Notices, Technical Standards Orders (TSO) and Advisory Circulars (AC) that will be utilized to collect methods of compliance for hardware and software design assurance levels, system safety analysis, special conditions, and equivalent levels of safety. The Society of Automotive Engineers (SAE) International's online database, SAE MOBILUS, will be utilized to find existing SAE articles and SAE Aerospace Recommended Practices (ARPs) that can be utilized as methods of compliance for the proposed fully autonomous aircraft. SAE ARPs such as ARP6128 is an industry consensus document that proposes common terminology for unmanned systems that can be adopted to establish common ground between entities that are working on these systems. Other documents such as their published scholarly articles may aid in determining MOCs for the UAM aircraft. For example, when combining the regulatory basis for a manned rotorcraft 14 CFR Part 27, SAE's unmanned aircraft system safety and development assurance may fill gaps that current manned rotorcraft regulations do not currently address.

Research articles related to UAM from scholarly sources such as American Institute of Aeronautics and Astronautics (AIAA) and NASA provide insight to the overall scheme of UAM operations within the National Airspace system. NASA has proposed a model for the utilization of UAM aircraft to revolutionize travel in congested urban areas by leveraging novel electric and VTOL technology to transport cargo and passengers. NASA has funded researchers to conduct analysis on all topics related to UAM from economic feasibility to vertiport infrastructure that will be required to conduct operations. While several NASA UAM topics are outside of the scope of individual aircraft certification, consideration of these elements may need to be leveraged when determining ELOS and other MOC. The AIAA has published research on UAM aircraft and operational certification. In the AIAA report, *Paths to Autonomous Vehicle Operations for Urban Air Mobility*, the concept of operations for UAM is detailed and presents the challenges for certifying large, uncrewed, passenger-carrying aircraft that operate over urban areas. When creating the certification basis, articles such as this one can be utilized to determine applicability of existing regulations and will aid in forging MOC.

Results

Utilizing the UAM aircraft CONOPS, and planned methodology, a Type Certificate (TC) Compliance Checklist was developed for the notional rotorcraft. The TC Compliance Checklist in the Appendix was applied to 14 CFR Part 27-Certification of Normal Category Rotorcraft to create a robust and unambiguous certification basis for the notional fully autonomous uncrewed passenger carrying UAM aircraft. Advisory Circular 27-1B (AC27-1B) provided specific guidance for typical methods of compliance for Normal Category Rotorcraft certification. Typical methods of compliance included methods such as engineering analysis (AN), where analytical or computational data is utilized to prove that a component meets safety, performance or operational standards. Flight and ground tests (FT and GT) were another commonly referred to method of compliance for certification standards throughout 14 CFR Part 27.

The fully autonomous and pilotless nature of the notional aircraft flagged regulations that included the terms, “pilot”, “exceptional pilot skill”, “exceptional pilot alertness”, and “exceptional pilot strength”. The term “pilot” occurs over 122 times in 14 CFR Part 27. Many of these regulations were not applicable (N/A), therefore they did not require a request for an exemption, equivalent level of safety, special condition, or any other sort of regulatory relief. However, many of the regulations in 14 CFR Part 27 that are applicable to the notional UAM aircraft's design and CONOPS include onboard crew action or pilot terminology. In these cases, automation is fulfilling an existing or new role/action hence amendments to the existing regulations or special conditions for the current regulations must be applied as a method of compliance. Table 1 includes 14 CFR Part 27 regulations that require special conditions as methods of compliance and in some cases amended regulations due to regulatory gaps, non-applicable criteria-based airworthiness standards and "human-centric" terminology that are not compatible with the notional fully autonomous rotorcraft. These regulations present the regulatory barriers for the notional fully autonomous uncrewed passenger carrying UAM aircraft to obtain a Type Certificate under 14 CFR Part 27.

Table 1

14 CFR Regulations Requiring Special Conditions as Methods of Compliance.

14 CFR Regulations	Regulation Title	14 CFR Regulations	Regulation Title
§ 27.33	Main rotor speed and pitch limits.	§ 27.961	Fuel system hot weather operation.
§ 27.51	Takeoff.	§ 27.1041	General. (Cooling)
§ 27.75	Landing.	§ 27.1043	Cooling tests.
§ 27.141	General. (Flight Characteristics)	§ 27.1195	Fire detector systems.
§ 27.143	Controllability and Maneuverability.	§ 27.1303	Flight and navigation instruments. (General)
§ 27.171	Stability: general.	§ 27.1305	Powerplant instruments.
§ 27.173	Static longitudinal stability.	§ 27.1321	Arrangement and visibility. (Instruments: Installation)
§ 27.177	Static directional stability.	§ 27.1329	Automatic pilot system.
§ 27.351	Yawing conditions.	§ 27.1335	Flight director systems.
§ 27.395	Control system. (Control Surface and System Loads)	§ 27.1337	Powerplant instruments.
§ 27.671	General. (Control Systems)	§ 27.1357	Circuit protective devices.
§ 27.672	Stability augmentation, automatic and power-operated systems.	§ 27.1523	Minimum flight crew
§ 27.683	Operation tests.	§ B27.4	Static longitudinal stability. (Airworthiness Criteria for Helicopter Instrument Flight)
§ 27.951	General. (Fuel System)	§ B27.5	Static Lateral Directional Stability. (Airworthiness Criteria for Helicopter Instrument Flight)
§ 27.952	Fuel system crash resistance.	§ B27.6	Dynamic Stability. (Airworthiness Criteria for Helicopter Instrument Flight)
§ 27.953	Fuel system independence.	§ B27.7	Stability Augmentation System (SAS). (Airworthiness Criteria for Helicopter Instrument Flight)
§ 27.954	Fuel system lightning protection.	§ B27.8	Equipment, systems, and installation. (Airworthiness Criteria for Helicopter Instrument Flight)

Subpart A - General

The first subpart to 14 CFR Part 27 establishes baseline airworthiness standards for rotorcraft seeking airworthiness certification. Advisory Circular 27-1B provides guidance throughout Part 27 for airworthiness certification standards. Most notably, AC 27-1B provides guidance for applying special conditions. The notional rotorcraft includes many novel technologies and special conditions are leveraged throughout the certification basis to fill regulatory gaps. AC27-1B recognizes that “novel or unusual” is a subjective term and states that any technology that differs from current airworthiness standards would be considered “novel or unusual”. AC27-1B states that special conditions must be applied to any “novel or unusual” technologies and justification for each special condition is required (FAA, 1999, p.31). No significant changes or amendments are required in this subsection for the certification basis of the notional rotorcraft.

Subpart B - Flight

Methods of compliance within Subpart B were primarily straightforward and do not require special conditions or changes for the notional rotorcraft to comply with Normal Category Rotorcraft airworthiness standards. Flight test, analysis and ground tests were commonly referred to methods of compliance for several airworthiness standards within Subpart B. The first special condition request is in § 27.33-Main rotor speed and pitch limits. The notional fully autonomous rotorcraft will require autonomous management of the flight control system and rotor speed limits must be maintained via onboard flight control logic. AC27-1B provides guidance for procedural compliance methods but lacks guidance regarding automation. The EASA Special Condition Report, SC E-19, provides guidance for airworthiness standards for electric / hybrid propulsion systems. The notional rotorcraft’s propulsion system and flight control system can leverage this special condition report to justify a special condition as a method of compliance. SC E-19 includes performance-based airworthiness criteria stating that rotor overspeed shall not result in the rotor catastrophically failing, causing damage or other hazardous effects to safety of flight (EASA, 2021, p.17). Utilizing SC E-19 and Part 27, amendments should be suggested for § 27.33(b), § 27.33(c), § 27.33(e).

Takeoff and landing airworthiness standards (§ 27.51 and § 27.75) also include pilot action where autonomy will now fill the role. § 27.51-Takeoff and § 27.75-Landing airworthiness standards includes terminology such as the subjective phrase “exceptional pilot skill, alertness, or strength”. The notional pilotless rotorcraft must demonstrate a method of compliance equivalent to the already ambiguous “exceptional pilot skill”. Pilots are certified under 14 Part 61, which establishes baseline competence for aircraft operators. Currently there are no 14 CFR regulations that establish baseline autonomy competence for fully autonomous systems that can be utilized for the notional aircraft’s certification basis. While the certification of the autonomous flight control logic and baseline decision making is outside the scope of the report, a certification basis can still be completed with the established autonomy definitions discussed earlier in this report. A special condition would be requested, referencing the § 21.17(b) certifications of the Amazon Logistics Inc, MK27 and 3DRobotics H520-G durability and reliability standards to aid in showing acceptable compliance with takeoff and landing airworthiness standards . Both of these certifications utilize D&R methods via flight test to show that the aircraft and associated systems are both durable and reliable. The FAA also commented that the D&R testing required zero failures during testing for acceptable compliance (FAA, 2020, p. 5). Additionally, amended language for takeoff and landing airworthiness standards should be suggested to establish performance-based airworthiness criteria that encompasses fully autonomous and electrically powered aircraft.

Flight Characteristics, controllability, maneuverability, and stability in Subpart B also include regulatory gaps that are not comprehensive enough to certify the notional rotorcraft. The fully autonomous nature of the notional rotorcraft requires it to maintain stability and control without pilot intervention. Evaluation of the flight characteristics of the aircraft must be done through an engineering analysis and flight test (AN and FT). § 27.141 includes "exceptional pilot skill, alertness or strength" as baseline airworthiness criteria for general flying characteristics. § 27.171 includes pilot action for stability utilizing the term, "undue pilot fatigue or strain". As discussed above, autonomy will be filling the role of piloting skill and action. Human piloting skills certified under 14 CFR Part 61 must be met with a computationally equivalent flight control computer. § 27.143(e) discusses engine failure controllability and maneuverability referencing pilot reaction time. Again, the autonomy of the system fills the role of the pilot and would reference a one-second reaction time to implement a corrective action as suggested within the regulation. A special condition would be requested to certify that the fully autonomous rotorcraft does not exceed any flight control, structural, or propulsion system limits to meet performance standards already established in § 27.141, § 27.143, § 27.171, § 27.173, § 27.175, and § 27.177. D&R flight test and computational simulation would be utilized to earn special condition approval. Amended language would be suggested to reduce ambiguity in compliance methods and broaden the scope of applicability of these regulations.

Subpart C - Strength Requirements

The strength requirements enclosed in Subpart C of Part 27 primarily rely upon engineering analysis as a compliance method for airworthiness certification. Flight test is leveraged in some cases to substantiate analytical analysis with experimental analysis. § 27.351-Yawing conditions, includes pilot action such as "maximum pilot force" and includes design features such as control stops. The notional rotorcraft does not include in-cockpit controls, therefore does not include control stops. Terms such as "maximum pilot force" are not applicable either due to the lack of an onboard operator and in-cockpit controls. A special condition would be requested to certify the maximum yawing loads as described in § 27.351(b) and § 27.351(c). D&R flight test and computational simulations would provide requisite yaw loading data to gain approval of the requested special condition.

§ 27.359 Control surface and system loads within Subpart C present another set of certification challenges for the fully autonomous electric uncrewed passenger carrying rotorcraft. The notional multirotor aircraft maintains stability and control from electric brushless outrunner motors. These brushless motors utilize reactive torque forces to maintain stability and control of the rotorcraft. Multirotor aircraft are statically and dynamically unstable and require flight control computers to maintain stability and control. The control system that manages stability and control would be certified under § 27.359. A special condition would be requested to certify the flight control system loads via D&R flight test and ground test. Amended language would also be suggested to improve applicability to autonomous flight control systems. The regulations in Subpart C were not applicable due to the notional rotorcraft not including in-cockpit controls.

Subpart D - Design and Construction

The notional rotorcraft utilizes emerging and novel technologies in almost every portion of the design. The powerplant is fully electric, the control system is fully autonomous, the structure is made of carbon-fiber composite materials. This created non-trivial regulatory barriers in Subpart D of 14 CFR Part 27. § 27.671-General and § 27.672-Stability augmentation, automatic, and power-operated systems both present regulation that is not conducive for the notional rotorcraft's certification basis. § 27.671 requires "each control" to operate with smoothness, ease and positiveness and due to the lack of in-cockpit control, does not directly apply to the notional rotorcraft. A special condition would be requested to certify the fully autonomous control system in accordance with § 27.671(a) and § 27.671(b). Ground testing would provide the necessary analysis for special condition approval.

The referred to, "stability augmentation system" of § 27.672 highlights the criteria-based airworthiness standards that limit the certification of novel technology. The notional fully autonomous rotorcraft inherently includes a flight control system that always maintains stability and control of the aircraft without pilot intervention. The flight control computer does every function the pilot is required for operation of the aircraft. Applicability of § 27.672 is analyzed in the discussion section contained within this report. For the sake of the certification basis, § 27.672 is deemed applicable and a special condition would be requested to certify the flight control stabilization portion of the fully autonomous flight controller. Standard operating conditions as well as control system failure must be tested, and D&R flight test and computational simulation can be utilized to provide test data that assures zero failure for the control system. Additionally, § 27.683-Operation tests would require a special condition to be applied to maintain applicability of the fully autonomous reactive torque control system. Inspection of the design to show that the brushless motors are free from jamming, excessive friction and deflection would show compliance with § 27.683 under a special condition. An additional subsection (d) would be suggested to allow for broader applicability to autonomous rotorcraft designs.

Subpart E - Powerplant

14 CFR Part 33 regulates airworthiness standards for aircraft engines. Subpart E of Part 27 adds additional compliance standards for rotorcraft powerplants. Fossil fuels have been and still are the primary fuel for aircraft powerplants. This has led to large regulatory gaps in current airworthiness standards. Additionally, much of Subpart E and Part 33 include criteria-based airworthiness standards that are not applicable to the notional rotorcraft's lithium battery powered, fully electric powerplant. § 27.951-General, regulates fuel system standards for rotorcraft powerplant's.

This is the first regulatory barrier in Subpart E as § 27.951 assumes entirely that fossil fuels are the only form of fuel utilized by a rotorcraft powerplant. AC 20-184 provides airworthiness standard guidance for the installation and testing of rechargeable lithium batteries. SC E-19 as discussed above also includes the EASA's special condition guidance for electric / hybrid propulsion systems. A special condition would be submitted for § 27.951 to establish general battery related fuel system requirements such as assuring that the lithium battery and associated battery system provides requisite energy for the powerplant to meet airworthiness standards. SC E-19 EHPS.380 Propulsion battery includes the EASA's special condition regulatory requirements for the powerplant's battery system (EASA, 2021, p. 24). An adaptation of this can be applied throughout Subpart E for fuel regulation standards. Additionally, the Part 33 special condition certification of the magniX USA electric powerplants include FAA approved methods for gaining airworthiness certification for an electric powerplant (FAA, 2021). § 27.952, § 27.953, § 27.954, § 27.961 all require special conditions for methods of compliance as current regulation does not consider non-fossil fuel related fuel systems. AC 20-184, AC27-1B, and the magniX USA certification include certification techniques such as ground and flight test to evaluate the safe operation of the battery powered powerplant in normal as well as degraded operations. For example, the battery system must be redundant and independent where a failed battery cell must allow for the safe recovery of the notional rotorcraft.

Amended language for all of these sections would be suggested and include performance-based airworthiness criteria to allow for electric powerplants and their associated fuel systems to be easily regulated under Part 27. Powerplant cooling contains another set of regulatory barriers for certification of the fully electric powerplant. Special conditions for § 27.1041 and § 27.1043 would be requested due to the non-applicability of fossil fuel related powerplant regulations. Special conditions from magniX USA's Part 33 certification can be leveraged to certify the cooling system of the notional rotorcraft. Additionally, SC E-19 EHPS.390 Cooling system provides generic cooling system certification standards for an electric / hybrid propulsion system. The notional rotorcraft's powerplant cooling system will be certified under a special condition in Part 27 through D&R ground testing and engineering analysis where adequate cooling must be provided throughout all flight altitudes and all flight regimes. Onboard fire detection capabilities also present another barrier to the creation of a comprehensive certification basis. The lithium batteries utilized by the notional rotorcraft can be highly flammable in certain circumstances. Additionally, the lack of onboard crew presents a non-trivial hazard for onboard fire detection capabilities. The onboard flight control computer must be able to detect fire, combat the identified fire and cope with degraded flight controls while determining an acceptable place to land. A special condition would be requested that would certify the onboard fire detection capabilities that are tailored specifically for electrical fires. Ground testing to satisfy durability and reliability requirements would allow for approval of the special condition. An additional subsection would be suggested that would provide performance-based airworthiness criteria for electric and autonomous fire detection systems to be certified directly by Part 27.

Subpart F - Equipment

The notional rotorcraft's required equipment highlights another large regulatory barrier for Part 27 certification. Flight equipment is typically installed for onboard pilot's or crew to view in order to operate the aircraft. The notional fully autonomous rotorcraft is pilotless and does not require human interaction to operate. Flight and navigation instruments, powerplant instruments, and their installation (§ 27.1303, § 27.1305, § 27.1337, § 27.1321) all would require a special condition to certify the telemetry data that will be displayed at a ground station that monitors the rotorcraft. Currently there are no applicable regulations in Part 27 that state which instruments are safety critical for a fully autonomous electrically powered rotorcraft. SC E-19 EHPS.360 Aircraft instruments provides guidance for electric powerplant aircraft instruments, stating ambiguously that a safety assessment should determine which instruments are required for display for an electric / hybrid propulsion system (EASA, 2021, p. 23). Additionally, the Amazon Logistics, Inc. MK27 § 21.17(b) certification provides a reference to what instruments are required to be displayed at the ground station. The FAA deemed the following were required to be displayed at the ground station: Alerts, status of any critical parameters for the energy storage system, all critical parameters of the propulsion system, flight and navigation parameters (airspeed, location and heading) and C2 link strength, quality or status (FAA, 2020, p. 5). The MK27 requires a certified pilot for operation, whereas the notional fully autonomous rotorcraft requires no human interaction to complete mission tasking. This could allow for reduced telemetry data requirements but for the purposes of this certification, this data would be transmitted for display to gain approval of the special condition. An additional subsection would be suggested that included performance-based airworthiness criteria that would clearly state which safety critical data must be transmitted for offboard monitoring.

The automatic pilot and flight director sections (§ 27.1329 and § 27.1335) of Subpart E within Part 27 assumes a human operator utilizing these systems to relieve the pilot of direct flight duties to reduce task saturation. This presents another large gap in Part 27 certification for a fully autonomous rotorcraft. As discussed earlier, an automatic pilot and flight director system are inherent in the flight control system of a fully autonomous aircraft. Applicability of sections § 27.1329 and § 27.1335 is included in the discussion section of this report and for the sake of developing a novel and comprehensive certification basis both of these sections will be considered applicable. § 27.1329 establishes requisite safety by requiring safe disengagement of the autopilot system and the skill of a certified pilot to safely operate the aircraft. The notional rotorcraft does not have a pilot and must include a computationally equivalent flight control computer to substitute a certified pilot. A special condition would be requested to certify the fully autonomous flight control system for both § 27.1329 and § 27.1335 through D&R ground and flight test as well as computational simulation. These tests would provide substantiation that the fully autonomous flight control system meets zero fail reliability standards.

Circuit protection devices (§ 27.1357) of Subpart E also includes pilot or onboard crew action to maintain safety of flight. Circuit breakers traditionally are designed to open a circuit when a fault is detected in order to prevent permanent damage to an electrical system. The breaker is then pushed back in by a human operator to close the circuit and restore the electrical system. The fully autonomous rotorcraft will need an autonomous circuit breaker detection and reset capability or only implement circuit breakers that do not require inflight reset and can be serviced by ground crew. A special condition would be requested for this regulation and D&R ground testing would provide requisite data for approval.

Subpart G - Operating Limitations and Information

Subpart G of Part 27 sets forth operating limitations and § 27.1523 requires a minimum flight crew to be established for airworthiness certification. The notional fully autonomous aircraft does not include an onboard crew for operation. Automation fills the role of the pilot and crew. This airworthiness standard is typically subjective and contingent upon pilot workload and types of operations. A special condition would be requested and show that Level 5 Autonomy established by the NHTSA and SAE J3016 is included in the fully autonomous rotorcraft and compliance with § 27.1329 and § 27.1335 removes the requirement for an onboard crew. An additional subsection would be suggested that would include performance-based airworthiness criteria for fully autonomous system certification.

Part 27 Appendices

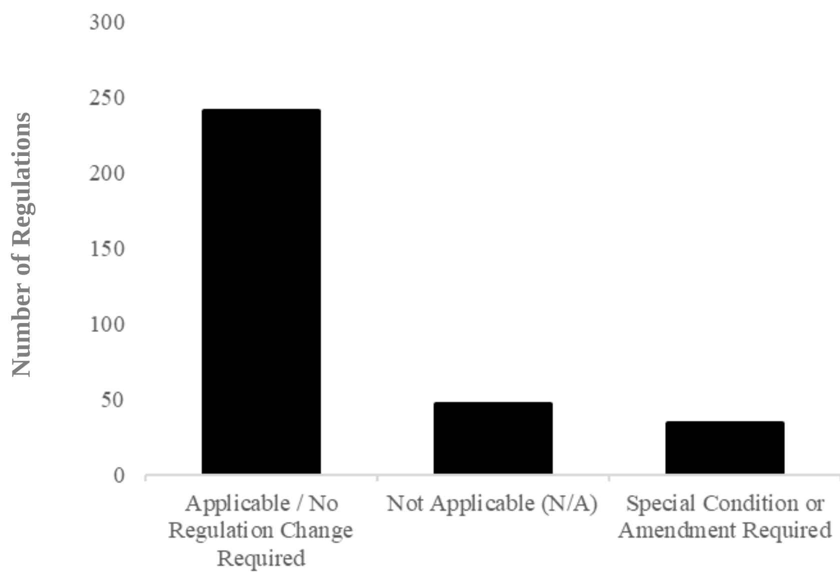
Static longitudinal, lateral-directional, and dynamic stability (§ B27.4, § B27.5, § B27.6) are actively managed by the onboard flight control system. Part 27 Appendix B requires compliance for rotorcraft operating in instrument meteorological conditions (IMC). The pilotless rotorcraft is fully autonomous and will require compliance with these IMC standards in order to operate in degraded weather conditions. These stability characteristics would be certified through a special condition request. This special condition request would include D&R flight and ground test to certify that the flight control system, structure and powerplant are not required to exceed certified limitations to maintain stability of the notional rotorcraft. Additionally, § B27.8- Equipment, systems, and installation would require a special condition as discussed above due to the lack of an onboard pilot. The § B27.8 special condition request would mirror the Subpart F -

Equipment special condition request. An additional subsection would be suggested that would include performance-based airworthiness criteria that would widen applicability to fully autonomous rotorcraft.

Amendment 27-50 of 14 CFR Part 27 contains 322 regulations of which 241 were directly applicable to the notional rotorcraft and require no changes or special conditions to meet airworthiness standards. Forty-seven Part 27 regulations do not have applicability due to the notional rotorcraft's design and CONOPS. Special conditions or amendments are required for 34 regulations for the notional rotorcraft to meet current airworthiness standards. Figure 1 depicts the current applicability of regulations within 14 CFR Part 27 to the notional electric fully autonomous passenger carrying UAM aircraft.

Figure 1

14 CFR Part 27 Regulation Applicability to the Notional Fully Autonomous Uncrewed Passenger Carrying UAM Aircraft



Discussion

Title 14 CFR Part 27 certification of the notional fully autonomous rotorcraft allows for the adaptation of current regulations to meet modern technological standards. The electric propulsion system and fully autonomous capability of the notional rotorcraft introduces a novel technology that is currently regulated by certification standards that were developed with the assumption that a human flight crew was aboard the aircraft. In some cases, regulations were not applicable due to the omission of unnecessary systems such as in-cockpit controls and pilot required instruments. Most of Part 27 remained applicable to the notional rotorcraft due to the performance and controllability nature of the airworthiness criteria. Several regulations, however, were partially applicable or require amendments or additional subsections to be completely applicable to a fully electric, fully autonomous rotorcraft. Amendments are suggested that contain performance-based airworthiness criteria and assure the safety intent in the previous prescriptive or criteria-based standards are met with requisite safety. Safety objectives for these novel technologies must be established to provide a clear path for certification. Additionally, consensus standards are leveraged to determine these new performance-based airworthiness criteria. This will allow for the quick development and adoption of these technologies and encourage innovation. These amendments and additions are discussed below in their applicable Subparts.

Subpart A - General

Sections § 27.1 and § 27.2 set the stage for the development of the certification for the notional rotorcraft. Section § 27.1 establishes that Part 27 is the regulatory standard for airworthiness certification of Normal Category Rotorcraft which includes aircraft with design features that are utilized by the notional rotorcraft. Subpart A is fully applicable to the notional rotorcraft and does not require any special methods of compliance or amendments to current regulations. Methods of compliance for Subpart A are met through apparent design features of the notional rotorcraft.

Subpart B - Flight

The requested special conditions in Subpart B relate to the flight control computer's ability to manage the propulsion system limits. The notional rotorcraft utilizes a novel, 16-rotor configuration with each rotor directly attached an associated electric brushless outrunner motor. Stability and control is provided through differential torque by instantaneous changes in motor RPM. This requires computing power provided by a flight control system that is beyond the capabilities of manual control by a human pilot. Main rotor speed limits are inherently integrated into any multirotor flight control system which requires the precise monitoring and application of motor RPM to maintain control of the rotorcraft. Sections § 27.33(b), § 27.33(c), § 27.33(e) are centered on human-pilot integration utilizing airworthiness standards that include a pilot or require pilot action. Sections § 27.33(b) and § 27.33(e) specifically require an onboard warning for rotor overspeed or low speed for the pilot to be able to recognize in flight, hence is not applicable to an uncrewed aircraft. However, the onboard automation of the notional aircraft will be required to monitor for rotor overspeed. Section § 27.33(c) also prohibits "exceptional piloting skill" to prevent rotor overspeed. Amended language or an additional subsection, stating," The flight control system must not exceed certified operational limits to prevent overspeed" would broaden § 27.33 applicability and provide performance-based airworthiness criteria for applicants to consider.

Take-off and landing requirements in Part 27, § 27.51 and § 27.75 include the same terminology used previously, utilizing "exceptional piloting skill" as the regulatory limitation for take-off and landing airworthiness. The notional rotorcraft takes off and lands autonomously and must include computationally equivalent decision-making to avoid inflight hazards during take-off and landing phases of flight. Revision of § 27.51 is suggested to include an additional subsection (c), stating, "Pilotless rotorcraft must have the ability to autonomously abort a take-off due to degraded C2 link or rotorcraft flight control, propulsion or structural failures." The Amazon Logistics Inc. MK27 and the 3DRobotics H520-G are both aircraft that utilized D&R test methods to successfully approve their special condition requests and can be leveraged to approve a special condition request as a method of compliance for the notional rotorcraft.

Flight characteristics, including performance, stability, and control, under 14CFR Part 27 are primarily evaluated by an onboard pilot to determine the aircraft's flying characteristics. The notional rotorcraft utilizes automation to evaluate the rotorcraft's real time attitude, speed, location, performance, and other onboard data to make appropriate self-correcting flight control inputs to execute the assigned mission. General flight characteristics, controllability, maneuverability, and stability derivatives regulated by Part 27 (§ 27.141, § 27.143, § 27.171, § 27.173, and § 27.177) all include terminology that requires pilot action or an onboard pilot. Automation fills the Pilot in Command's (PIC) role of controlling and monitoring the aircraft's state. Exceptional pilot skill, alertness or strength is subjective. However, certified pilots have an established baseline of competence through training, proficiency and ultimately certification standards regulated by 14 CFR Part 61.

Maximum task loading or strength requirements a pilot is able to withstand determines what constitutes "exceptional". Task loading includes number of steps, memory load, checklist use, time-to-perform, and training requirements. Any task loading or strength requirement that is considered to exceed the capabilities of the pilots who normally fly the type of aircraft being certified constitutes "exceptional". In terms of a fully autonomous system, subjectivity can be removed in deterministic computerized systems. For example, reaction times, memory capacity or strength do not have to be subjectively determined. Computerized decision-making and computerized actions are limited by computational limits set by hardware and software. Determining computationally equivalent piloting skill is beyond the scope of this report but poses an interesting development for future works.

The certification basis for § 27.141, § 27.143, § 27.171, § 27.173, and § 27.177 will require a special condition. Flight test D&R criteria provide acceptable methods of compliance similar to the take-off and landing certification standards. General flight characteristics (§ 27.141) will require a special condition to show that the notional rotorcraft does not exceed or strain any flight control or propulsion system limits to meet requisite performance including transitions from hovering, climbing, descending and translational flight. An additional subsection (d) in § 27.141 is suggested, stating, "Pilotless rotorcraft must include flight control systems that are computationally equivalent to certified human piloting skills. These certified flight control systems must not exceed established limits to meet requisite flight characteristics to maintain stability and control in all regimes of flight." Controllability and maneuverability (§ 27.143) would follow the same special condition along with an additional subsection (g). Stability airworthiness standards (§ 27.171, § 27.173, § 27.177) would also utilize a special condition and additional subsections (§ 27.171(a), § 27.173(c), and § 27.177(d)) should utilize the same language as suggested for § 27.141 certification. Overall, for Subpart B regulations § 27.33, § 27.51, and § 27.75, § 27.141, § 27.143, § 27.171, § 27.173, and § 27.177, a special condition would satisfy as a method of compliance for creation of the certification basis.

Subpart C - Strength Requirements

The majority of Subpart C remains applicable and certification through engineering analysis, and ground and flight test can be utilized as acceptable methods of compliance. Yawing conditions (§ 27.351) in Subpart C introduces the first regulation that references pilot action. A special condition is required to show compliance that the notional fully autonomous rotorcraft can withstand maximum yawing loads that the aircraft may be subject to. An additional subsection (d) to § 27.351 would be suggested that states, "Pilotless rotorcraft shall induce maximum yawing conditions through maximum certified flight control logic to certify the loads as described in § 27.351(b) and § 27.351(c)."

Control systems are another area of autonomous novelty that the notional rotorcraft introduces for airworthiness certification. Control system airworthiness certification standards (§ 27.395) includes several pilot force requirements to assure that certified rotorcraft can withstand maximum control inputs. This will require a special condition via engineering analysis or D&R flight test criteria to prove that the notional rotorcraft's autonomy is in compliance with standards. The control system must withstand the maximum forces that the autonomous stability and control system are capable of generating. An additional section (c) to § 27.395 will be required, stating, "Pilotless rotorcraft control systems must withstand maximum certified loads resulting from maximum flight control forces from autonomous flight control logic."

Subpart D - Design and Construction

Airworthiness criteria for the design and construction of the notional rotorcraft remains mostly applicable throughout the certification basis. Only three portions of Subpart D require a special condition. The language utilized in airworthiness standards for control system design and construction is not entirely applicable to the notional rotorcraft due to the lack of onboard flight controls. Special conditions would be requested for § 27.671, § 27.672 and § 27.683 to provide the required verification that the notional rotorcraft is in compliance with design and construction standards. General control system design and construction standards, the stability augmentation system and the operational tests include airworthiness standards that are pilot centric. Special conditions must be requested to adequately address these airworthiness standards that have partial applicability to the notional rotorcraft. General and operational tests of the control system design (§ 27.671 and § 27.683) include wording that starts with the baseline assumption that all rotorcraft include in-cockpit controls. This is not true for the notional fully autonomous design and will require a special condition request to satisfy requirements that require control systems to be free of any excessive friction or strain.

The stability augmentation system (SAS) section, § 27.672, has reasonable applicability to the notional rotorcraft since the stability augmentation is inherently included with a fully autonomous flight control system. Airworthiness criteria for SAS is intended to be applied to piloted rotorcraft that have SAS designs to provide pilot relief while operating the rotorcraft. However, SASs include automation in their design and operation and design and construction of the automated system is applicable to the notional rotorcraft. Due to Subpart D relating to the design and construction of the automation system, the SAS airworthiness criteria will be considered applicable to the notional rotorcraft's airworthiness. A special condition would be requested to satisfy airworthiness requirements that mandate an alert is made noticeable anytime there is a degradation in any of the rotorcraft's SAS or automated power systems. An additional subsection (d) would be suggested, stating, "Pilotless rotorcraft must comply with all subsections of § 27.672 where stability augmentation failures must be autonomously recognized and autonomously counteracted to maintain autonomous stability and control of the rotorcraft."

Subpart E - Powerplant

Electric powerplant certification is one of the largest gaps in regulation and consequently requires the most special conditions for airworthiness certification of the notional rotorcraft. The design utilizes a fully electric powerplant with fully autonomous control, introducing two novel technologies into the legacy regulations. Title 14 CFR Part 33, regulates airworthiness standards for aircraft engines and must be complied with throughout Part 27's Subpart E. Both Part 27 Part E and Part 33 are internal combustion engine-centric regulations. With little applicability to a fully electric and autonomous powerplant and fuel system. The FAA has released several Special Class airworthiness certificates that provide guidance for D&R test criteria and special condition certification as well as ACs that provide regulatory guidance for electric and Lithium battery propulsion systems. The EASA special condition report, SC E-19, also provides useful definitions and generic airworthiness criteria related to electric / hybrid propulsion systems.

Fuel system regulatory requirements that start with § 27.951 and continue through § 27.954 require special conditions to accommodate an electric powerplant. The magniX USA powerplant Part 33 special condition certification can be leveraged throughout Subpart E as this certification received several rulings from the FAA on fully electric powerplant certification. An additional subsection for § 27.951 would be required that states, "If an electric powerplant is powered by a electro-chemical battery, the battery and associated battery management system must be designed and built to provide requisite power to the electric powerplant to assure the rotorcraft meets performance and mission requirements." Fuel system independence airworthiness (§ 27.953) would also have an additional subsection requested, that states, "If an electric powerplant is powered by a electro-chemical battery, the battery, motor controller and associated battery management system must be fully independent and allow for full engine operation with failed battery cells, failed motor controllers, or failed battery management systems." Fuel system lightning protection (§ 27.954) would also have an additional subsection suggested that states, "If an electric powerplant is powered by an electro-chemical battery, the battery system must be designed and arranged to prevent ignition of the battery due to lightning strikes and lightning conditions described in § 27.954(a)-§ 27.954(b)." These suggested performance-based airworthiness criteria additions would allow for broadened airworthiness standards and reduce limitations in certifying novel electric-based powerplant fuel systems.

An additional adverse weather airworthiness criteria for fuel system hot weather operation (§ 27.961) also requires a special condition as terms such as fuel vapor and specific temperatures such as 110 degrees Fahrenheit are all fossil fuel criteria-based airworthiness standards that are not directly applicable to a fully electric propulsion system. The magniX USA certification and AC 20-184 were referenced to develop a suggested subsection (a), stating, “Rotorcraft utilizing electric power plants powered by electro-chemical batteries must meet established powerplant performance standards in hot weather conditions and degraded battery states and additional conditions set forth in § 27.927.”

Electric powerplant cooling is the next set of airworthiness standards in Subpart E that require special conditions for a full certification basis. Current powerplant cooling regulations in Part 27 are fossil fuel centric. Cooling test regulation currently includes criteria-based airworthiness criteria that is not directly applicable to an electric powerplant. The magniX USA special condition certification provides cooling special condition approval that would be utilized for the notional rotorcraft’s fully electric powerplant special condition certification. The magniX USA certification includes the FAA’s requirement that the powerplant be designed and constructed to produce adequate cooling in conditions that the aircraft is expected to operate (FAA, 2021, p. 6). Additionally, the Joby JAS4-1 certification includes powerplant cooling requirements that include safety standards such as the powerplant being required to operate safely in a degraded state (FAA, 2022, p. 8).

Powerplant fire protection and fire detector systems (§ 27.1195) require special condition requests due to the Lithium energy storage system. Lithium batteries are susceptible to fire under certain conditions and special care must be included to assure their safe installation, use and maintenance. AC 20-184 includes provisional guidance for the safe installation and usage of Lithium batteries onboard aircraft. AC 20-184 lists types of electrical failures that lead to high probabilities of fire and includes considerations for thermal runaways caused by various errors (FAA, 2015, p. 6). Additionally, the fully electric Joby JAS4-1 certification includes FAA regulatory special condition requirements for onboard fire. Utilizing the JAS 4-1 certification and AC 20-184 an additional subsection (a) to § 27.1195 would be required, stating, “Pilotless rotorcraft must include autonomous fire detection, fire suppression and flight control casualty management that assures stability and control of the rotorcraft in the event of an onboard fire."

Subpart F - Equipment

The novelty of an unmanned design creates ambiguity with any regulations that require pilot action, flight crew interaction or any onboard flight crew consideration. Onboard displays for the notional rotorcraft are not applicable as their information would be trivial to passengers because of the lack of an onboard pilot. Required flight, navigation, and powerplant instruments, their arrangement and installation (§ 27.1303, § 27.1305, and § 27.1321, § 27.1337) would be a requested special condition in order to display required in-cockpit displays to a ground station. Transmission of these instruments for offboard monitoring may provide a ground station or air traffic control (ATC) the ability to see live aircraft system information. Again, since the notional rotorcraft is fully autonomous, there would be no requirement for ground crew to be able to take full control and fly the aircraft. Displayed data would just be transmitted for descriptive updates on aircraft health and flight status comparable to transponder or Automatic Dependent Surveillance-Broadcast (ADS-B). The Amazon Logistics Inc. MK27 aircraft certification includes the FAA requirement that the ground station must provide pilots with aircraft information necessary for safe operation (FAA, 2020, p. 2). Due to the lack of pilot interaction onboard as well as offboard, any information transmitted to a ground station would not be legally required but provide useful status updates for ground-based crew. Performance-based airworthiness criteria would be suggested for § 27.1303, § 27.1305, § 27.1321, and § 27.1337 stating, "Pilotless rotorcraft do not require in-cockpit instruments to be displayed but must transmit rotorcraft safety critical data for offboard monitoring."

Similar to the discussion of SAS, the certification of the automatic pilot system and flight director system within Part 27 infers that these systems are utilized as pilot relief modes to reduce pilot workload. The notional rotorcraft is fully autonomous and inherently utilizes these technologies constantly to execute the assigned mission. A special condition would be submitted for § 27.1329 and § 27.1335 and utilize D&R test criteria to earn airworthiness approval. Flight test as well as computational simulation would be utilized to execute D&R testing. An amendment to both § 27.1329 and § 27.1335 would be suggested, stating, "Pilotless rotorcraft must have a certified flight control computer that substitutes certified pilot skill to maintain complete autonomy throughout operation and shall not exceed certified computational, flight control, structural, or propulsion limits to maintain routing or safety of flight."

Circuit protective devices add an additional complication to certification as their entire design requires in-cockpit reset by onboard crew. A special condition would be requested to certify the notional rotorcraft's circuit protective device logic. The notional rotorcraft would autonomously detect circuit faults, isolate these faults and mitigate inflight hazards through either resetting tripped circuits or continuing the assigned mission with acceptable levels of degradation. D&R ground and flight test would provide required data for FAA special condition approval pending zero test failures.

Subpart G - Operating Limitations and Information

Subpart G largely applies to the notional rotorcraft as limits are established for safe operation of the aircraft's subsystems. Minimum flight crew (§ 27.1523) is the only special condition request within Subpart G due to the non-applicability of any crew requirement for operation of the notional rotorcraft. All operations of the notional rotorcraft and decision making is made with "human-out-of-the-loop" technology and only initialization and maintenance require human interaction. While typically a subjective airworthiness standard due to its human-centric requirements, it becomes an objective standard as long as the aircraft meets the definition of fully autonomous. Any level of autonomy below fully autonomy, would require consideration of § 27.1523 due to partial or complete human interaction. An amendment to § 27.1523 would be suggested via an additional subsection that would state, "Fully autonomous, pilotless rotorcraft require no flight crew onboard given compliance with § 27.1329 and have equivalent levels of safe autonomy to that of SAE International or NHTSA Level 5 Autonomy."

Appendices

The notional rotorcraft's CONOPS include the possibility of instrument flight making Appendix B to Part 27 fully applicable to the notional rotorcraft. The stability and equipment requirements within the appendix (§ B27.4, § B27.5, § B27.6, § B27.7, and § B27.8) require special conditions to be applied and would follow the same stability, controllability and general flight characteristics certification techniques listed in Subpart B certifications. Static longitudinal stability, static lateral-directional stability, and dynamic stability would request a special condition to certify that the electric motors providing propulsion do not exceed certified limits to maintain stability and controllability in any flight regime. Amendments in the form of additional subsections would be suggested, stating, "Pilotless rotorcraft must have a certified computationally equivalent flight control computer that would substitute certified pilot skill and shall not exceed certified computational, flight control, structural, or propulsion limits to maintain static and dynamic stability." Engineering analysis, flight test and computational simulation would be leveraged to provide data that the stability derivatives of the notional rotorcraft do not exceed the capabilities of the flight control system. The SAS would be certified under the same special condition request as listed in § 27.672, § 27.1329, and § 27.1335 which would certify the entire fully autonomous flight control system.

Additionally, § B27.8-Equipment, systems, and installation, would also include a special condition request that would mirror the certification techniques utilized by Subpart F certification. In-flight telemetry would only be required for rotorcraft status and flight status updates. An additional subsection (c) that includes performance-based airworthiness criteria would be suggested, stating, “Pilotless rotorcraft do not require in-cockpit instruments to be displayed but must transmit rotorcraft safety critical data for offboard monitoring.” Overall, Appendix B to Part 27 certification would utilize the same techniques as used in Subparts A-G and would enable instrument flight in degraded weather conditions for the notional rotorcraft.

Conclusions

The creation of a fully autonomous uncrewed passenger carrying rotorcraft for implementation in NASA’s Urban Air Mobility CONOPS required significant regulatory rulemaking action. Current certification procedures slow the advancement of fully autonomous electric aircraft. The certification basis developed in this study for a notional 16-rotor uncrewed passenger carrying fully autonomous UAM rotorcraft provides unambiguous methods of compliance and clear mapping to industry research and standards. Current Part 27 regulations are mostly applicable to the notional rotorcraft as 241 regulations remain fully applicable while 47 are not applicable. Thirty-four regulations require changes or non-standard methods of compliance. Special conditions for these 34 regulations complete the requirements for a deliberate and defensible certification basis. Additionally, examination of current literature allowed the development of amendments or additions to current Part 27 regulations via performance-based airworthiness criteria to broaden applicability to fully autonomous and electric rotorcraft systems. Working definitions for full autonomy are referenced from the automobile industry albeit autonomy in automobiles only requires two-dimensional considerations. Fully autonomous flight control logic must be able to operate the aircraft safely in all operational flight regimes as well as include the ability to avoid or mitigate in-flight hazards. The use of the terms “exceptional pilot skill”, “exceptional pilot alertness”, and “exceptional strength” presented several required changes throughout Part 27 as autonomy fills the role of the pilot in the notional rotorcraft. A computationally equivalent, fully autonomous flight control computer must replace the skills, alertness, and strength of a 14 CFR Part 61 certified pilot. Determining computational equivalence for human cognition is outside the scope of this report and presents compelling analysis for future work.

Certification of the fully electric propulsion system is another area of regulatory uncertainty as current powerplant certification standards in Part 27 as well as Part 33 were written for fossil-fuel based propulsion systems. Special conditions are required throughout Subpart E to provide an equivalent level of compliance for the novel propulsion system. Considering the FAA’s special condition requests, ACs, § 21.17(b) certifications and literature such as the EASA’s SC E-19, additions and amendments to Part 27 regulations regarding powerplant certification are suggested. Mainly, electric powerplants and their related energy storage systems such as Lithium batteries must include performance-based airworthiness criteria. These criteria must include safe operations in hazardous or degraded states.

The continued adoption of autonomous and electric systems will advance the development of these technologies as well as improve the scope and clarity of certification criteria. Expanding the applicability of current Part 27 regulations to accommodate these technologies will expedite the certification process and the introduction of these types of aircraft into the NAS.

Recommendations

Pilot competence is currently certified under 14 CFR Part 61. Pilots are required to meet airman certification standards (ACS) for alertness, skill, and strength in order to operate aircraft safely under normal, abnormal, and emergency conditions. However, the notional rotorcraft is fully autonomous and utilizes autonomous flight control algorithms to execute the Urban Air Mobility mission. Consequently, in lieu of pilot competence, autonomous decision-making through the onboard artificial intelligence (AI) must be certified. Therefore, further research on certifying the integrated AI on the notional rotorcraft is recommended.

In addition to certification of the onboard AI, certification standards for electric motors and electric storage systems could be furthered by a more intensive review of current automobile electric motor and energy storage system certification standards. Portions of Subpart E remain ambiguous as electric motors and Lithium battery technology is still under development. More stringent specificity may be required to assure that appropriate levels of safety are included in electric powerplant certification. The automobile industry is currently experiencing a technological revolution as automobile manufacturers have started to shift from fossil-fuel based automobiles to fully electric vehicles with some manufacturers promising eventually to only produce electric vehicles. Companies such as Tesla, Inc. currently only produce fully electric, Lithium powered automobiles. These automobile manufacturers are creating an enormous volume of Lithium battery systems and electric propulsion systems. The extant research only considered automotive standards for autonomy and did not reference any specific automotive electric motor or Lithium battery certification standards. Leveraging automobile manufacturers experiences, techniques and procedures would aid in a more intensive development of aircraft electric propulsion system certification.

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Appendix. Fully Autonomous Uncrewed Passenger Carrying UAM Aircraft Type Certificate Compliance Checklist

Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1	Applicability.	27-37	-	-	Compliance shown in subparagraphs.
§ 27.1(a)	-	27-37	DE	AC 27-1B	
§ 27.1(b)	-	27-37	DE	AC 27-1B	
§ 27.1(c)	-	27-37	DE	AC 27-1B	
§ 27.2	Special retroactive requirements.	27-37	-	-	Compliance shown in subparagraphs.
§ 27.2(a)(1)-§ 27.2(a)(4)	-	27-37	AN,GT	AC 27-1B	
§ 27.2(b)(1)-27.2(b)(2)	-	27-37	DE	AC 27-1B	
Subpart B - Flight					
§ 27.21	Proof of compliance.	27-21	-		Compliance shown in subparagraphs.
§ 27.21(a)-§ 27.21(b)	-	27-21	FT,GT	AC 27-1B	
§ 27.25	Weight limits.	27-44	-		Compliance shown in subparagraphs.
§ 27.25(a)	Maximum weight.	27-44	AN,FT	AC 27-1B	
§ 27.25(b)	Minimum weight.	27-44	AN,FT	AC 27-1B	
§ 27.25(c)	Total weight with a jettison able external load.	27-44	N/A		The notional rotorcraft does not include an external payload.
§ 27.27	Center of gravity limits.	27-2	-		Compliance shown in subparagraphs.
§ 27.27(a)-§ 27.27(c)	-	27-2	AN,FT	AC 27-1B	
§ 27.29	Empty weight and corresponding center of gravity.	27-14	-		Compliance shown in subparagraphs.
§ 27.29(a)-§ 27.29(b)	Empty weight and corresponding center of gravity.	27-14	AN,FT,GT	AC 27-1B	

*Methods of Compliance:
FT = Flight Test, GT = Ground Test, AN = Analysis, DE = Design, SC = Special Condition, SI = Similarity, ELOS = Equivalent Level of Safety Finding, PExmpt = Petition for Exemption, N/A = Not Applicable

Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.31	Removable ballast.	Initial	N/A		The notional rotorcraft does not include a ballast.
§ 27.33	Main rotor speed and pitch limits.	27-14	-		Compliance shown in subparagraphs.
§ 27.33(a)	Main rotor speed limits.	27-14	AN,FT,GT	AC 27-1B	
§ 27.33(b)	Normal main rotor high pitch limits (power on).	27-14	AN,FT,GT,SC	AC 27-1B EASA Special Condition SC E-19-Electric/Hybrid Propulsion System (EHPS.240 Overspeed and Rotor Integrity) SC No. FAA-2021-0638 (Joby Aero, Inc. JAS4-1)	A special condition would be requested for subpart (b)(3) as the notional rotorcraft is pilotless. Amended language would be suggested, stating, "Rotor overspeed must be monitored by the flight control system for the onboard logic to prevent." EASA SC EHPS.240 and the Joby Aero Inc. JAS4-1 provides additional reference for electric propulsion overspeed and rotor integrity certification standards.

*Methods of Compliance:
FT = Flight Test, GT = Ground Test, AN = Analysis, DE = Design, SC = Special Condition, SI = Similarity, ELOS = Equivalent Level of Safety Finding, PExmpt = Petition for Exemption, N/A = Not Applicable

Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.33(c)	Normal main rotor off pitch limits (power off).	27-14	AN,FT,GT,SC	AC 27-1B EASA Special Condition SC E-19-Electric/Hybrid Propulsion System (EHPS.240 Overspeed and Rotor Integrity)	A special condition would be requested for subpart (c)(2) as the notional rotorcraft is pilotless. Rotor overspeed must be monitored by the flight control system for the onboard logic to prevent. Amended language would be suggested, stating, "The flight control system must not exceed certified operational limits to prevent overspeed." EASA SC EHPS.240 provides reference for electric propulsion overspeed and rotor integrity certification standards.
§ 27.33(d)	Emergency high pitch.	27-14	AN,FT,GT	AC 27-1B	
§ 27.33(e)	Main rotor low speed warning for helicopters.	27-14	AN,FT,GT,SC	AC 27-1B EASA Special Condition SC E-19-Electric/Hybrid Propulsion System (EHPS.240 Overspeed and Rotor Integrity)	A special condition would be requested for subpart (e) as the notional rotorcraft is pilotless. Rotor speed must be monitored by the flight control system for the onboard logic to determine engine failure. Amended language would be suggested, stating, "The flight control system must not exceed certified operational limits to compensate for engine failure." EASA SC EHPS.240 provides reference for electric propulsion overspeed and rotor integrity certification standards.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.45	General.	27-21	-		Compliance shown in subparagraphs.
§ 27.45(a)	-	27-21	AN,FT,GT	AC 27-1B	
§ 27.45(b)	-	27-21	AN,FT,GT	AC 27-1B	
§ 27.45(c)	-	27-21	AN,FT,GT	AC 27-1B	
§ 27.45(d)-§ 27.45(f)	-	27-21	N/A		Non-Reciprocating / Non-Turbine
§ 27.49	Performance at minimum operating speed.	27-44	-		Compliance shown in subparagraphs.
§ 27.49(a)	-	27-44	FT	AC 27-1B	
§ 27.49(b)	-	27-44	FT	AC 27-1B	
§ 27.51	Takeoff.	27-44	-		Compliance shown in subparagraphs.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.51(a)	-	27-44	FT,SC	AC 27-1B SC No. FAA-2020-1083 (3DR-GS H520-G) SC No. FAA-2020-1086 (Amazon Logistics, Inc. MK27)	A special condition would be submitted to certify the takeoff performance of the notional rotorcraft to certify that it does not exceed flight control limits or propulsion system limits to meet requisite takeoff performance. An additional section (c) would be suggested, stating, "Pilotless rotorcraft must have the ability to autonomously abort a takeoff due to degraded C2 link or rotorcraft flight control, propulsion or structural failures." Durability and reliability requirements from the Amazon MK27 and 3DRobotics H520-G § 21.17(b) certifications provide reference for unmanned rotorcraft landing certification standards.
§ 27.51(b)	-	27-44	FT	AC 27-1B	
§ 27.65	Climb: All engines operating.	27-33	-		Compliance shown in subparagraphs.
§ 27.65(a)	-	27-33	FT	AC 27-1B	
§ 27.65(b)	-	27-33	FT	AC 27-1B	
§ 27.67	Climb: one engine inoperative.	27-23	-		Compliance shown in subparagraphs.
§ 27.67(a)	-	27-23	AN,FT	AC 27-1B	
§ 27.67(b)	-	27-23	AN,FT	AC 27-1B	
§ 27.71	Autorotation performance.	27-44	-		Compliance shown in subsections.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.71(a)-§ 27.71(b)	-	27-44	FT	AC 27-1B	
§ 27.75	Landing.	27-44	-		Compliance shown in subparagraphs.
§ 27.75(a)	-	27-44	FT,SC	SC No. FAA-2020-1083 (3DR-GS H520-G) SC No. FAA-2020-1086 (Amazon Logistics, Inc. MK27) AC 27-1B	A special condition would be submitted to certify the landing performance of the notional rotorcraft to certify that it does not exceed flight control limits or propulsion system limits to meet requisite landing performance. An additional section (c) would be suggested, stating, “Pilotless rotorcraft must have the ability to autonomously land during degraded C2 link or rotorcraft flight control, propulsion or structural failures.” Durability and reliability requirements as well as contingency planning from the Amazon MK27 and 3DRobotics H520-G § 21.17(b) certifications provide reference for unmanned rotorcraft landing certification standards.
§ 27.75(b)	-	27-44	FT	AC 27-1B	
§ 27.87	Height-speed envelope.	27-44	-		Compliance shown in subparagraphs.
§ 27.87(a)	-	27-44	FT	AC 27-1B	
§ 27.87(b)	-	27-44	FT	AC 27-1B	
§ 27.141	General.	27-21	-		Compliance shown in subparagraphs.
§ 27.141(a)	-	27-21	FT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.141(b)	-	27-21	AN,FT,SC	AC 27-1B	A special condition would be submitted to certify the notional rotorcraft's general flying characteristics. This special condition would certify that the rotorcraft does not exceed or strain any flight control or propulsion system limits to meet requisite performance including transitions from hovering, climbing, descending and translational flight. An additional subsection (d) would be suggested, stating, "Pilotless rotorcraft must include flight control systems that are computationally equivalent to certified human piloting skills. These certified flight control systems must not exceed established limits to meet requisite flight characteristics to maintain stability and control in all regimes of flight."
§ 27.141(c)	-	27-21	FT	AC 27-1B	
§ 27.143	Controllability and maneuverability.	27-44	-		Compliance shown in subparagraphs.
§ 27.143(a)	-	27-44	FT	AC 27-1B	
§ 27.143(b)	-	27-44	N/A		The notional rotorcraft does not include cyclic control.
§ 27.143(c)	-	27-44	FT	AC 27-1B	
§ 27.143(d)	-	27-44	FT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.143(e)	-	27-44	FT,SC	AC 27-1B	A special condition would be submitted to certify the notional rotorcraft's flight control computer reacts with at least a reaction time of at least one second as referenced in AC27-1B.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.143(f)	-	27-44	FT,SC	AC 27-1B	A special condition to certify the notional rotorcraft's controllability and maneuverability would be submitted to certify that the rotorcraft does not exceed any flight control or propulsion system limits to meet requisite controllability and maneuverability performance. Certified pilot skill would be substituted by a certified computationally equivalent flight control computer that meets standards for stability and control through durability and reliability field testing and computerized simulation. An additional section (g) with performance based requirements would be suggested, stating, "Pilotless rotorcraft will substitute certified pilot skill with a certified computationally equivalent flight control computer that does not exceed certified limits to maintain requisite controllability and maneuverability as established in § 27.143."
§ 27.151	Flight controls.	27-21	N/A		The notional rotorcraft does not include in-cockpit flight controls.
§ 27.161	Trim control.	27-21	N/A		The notional rotorcraft does not include in-cockpit trim controls.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.171	Stability: general.	Initial	FT,SC	AC 27-1B	A special condition to certify the notional rotorcraft's stability would be submitted to certify that the rotorcraft does not exceed certified flight control or propulsion system limits to meet requisite stability requirements. A subsection (a) would be suggested, stating, "Pilotless rotorcraft must not exceed certified flight control, structural or propulsion system limits, particularly fatigue limits for a period of time as long as that expected in normal operation."
§ 27.173	Static longitudinal stability.	27-44	-		Compliance shown in subparagraphs.
§ 27.173(a)	-	27-44	FT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.173(b)	-	27-44	FT,SC	AC 27-1B SC No. FAA-2020-1083 (3DR-GS H520-G) SC No. FAA-2018-0379 (Yamaha Fazer R)	A special condition to certify the notional rotorcraft's static longitudinal stability would be submitted to certify that the rotorcraft does not exceed any certified flight control or propulsion system limits to meet requisite stability requirements. Adding a performance-based airworthiness criteria in an additional subsection (c) would be suggested, stating, "Pilotless rotorcraft must have a certified computationally equivalent flight control computer that would substitute certified pilot skill and shall not exceed certified computational, flight control, structural, or propulsion limits to maintain static longitudinal stability." The requested special condition would be certified through durability and reliability testing via flight test and computational simulation where zero failure tolerance is required.
§ 27.175	Demonstration of static longitudinal stability.	27-44	-		Compliance shown in subparagraphs.
§ 27.175(a)	Climb.	27-44	FT	AC 27-1B	
§ 27.175(b)	Cruise.	27-44	FT	AC 27-1B	
§ 27.175(c)	V_{NE}.	27-44	FT	AC 27-1B	
§ 27.175(d)	Autorotation.	27-44	FT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.177	Static directional stability.	27-44	-		Compliance shown in subparagraphs.
§ 27.177(a)	-	27-44	FT	AC 27-1B	
§ 27.177(b)	-	27-44	FT,SC	AC 27-1B	A special condition would be requested to certify the notional rotorcraft's flight control computer. The flight control computer would be required to recognize and react to static directional stability limits and maintain stability and control as it reached its sideslip limits.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.177(c)	-	27-44	FT,SC	AC 27-1B	A special condition would be requested to certify the notional rotorcraft's static directional stability. This would certify that the rotorcraft does not exceed any flight control or propulsion system limits to meet requisite stability requirements. Adding a performance-based airworthiness criteria in an additional subsection (d) would be suggested, stating, "Pilotless rotorcraft must have a certified computationally equivalent flight control computer that would substitute certified pilot skill and shall not exceed certified computational, flight control, structural, or propulsion limits to maintain static directional stability." The requested special condition would be certified through durability and reliability testing via flight test and computational simulation where zero failure tolerance is required.
§ 27.231	General.	Initial	GT	AC 27-1B	
§ 27.235	Taxiing condition.	Initial	GT	AC 27-1B	
§ 27.239	Spray characteristics.	Initial	FT,GT	AC 27-1B	
§ 27.241	Ground resonance.	Initial	GT	AC 27-1B	
§ 27.251	Vibration.	Initial	GT	AC 27-1B	
Subpart C - Strength Requirements					

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.301	Loads.	Initial	-		Compliance is shown in subsections.
§ 27.301(a)-§ 27.301(b)	-	Initial	AN	AC 27-1B	
§ 27.303	Factor of safety.	Initial	AN	AC 27-1B	
§ 27.305	Strength and deformation.	Initial	-		Compliance is shown in subsections.
§ 27.305(a)-§ 27.305(b)	-	Initial	AN	AC 27-1B	
§ 27.307	Proof of structure.	27-26	-		Compliance is shown in subsections.
§ 27.307(a)-§ 27.307(b)	-	27-26	AN	AC 27-1B	
§ 27.309	Design limitations.	Initial	-		Compliance is shown in subsections.
§ 27.309(a)-§ 27.309(g)	-	Initial	AN	AC 27-1B	
§ 27.321	General.	27-11	-		Compliance is shown in subsections.
§ 27.321(a)-§ 27.321(b)	-	27-11	AN	AC 27-1B	
§ 27.337	Limit maneuvering load factor.	27-26	-		Compliance is shown in subsections.
§ 27.337(a)-§ 27.337(b)	-	27-26	AN,FT	AC 27-1B	
§ 27.339	Resultant limit maneuvering loads.	27-11	AN	AC 27-1B	
§ 27.341	Gust loads.	Initial	AN	AC 27-1B	
§ 27.351	Yawing conditions.	27-34	-		Compliance is shown in subsections.
§ 27.351(a)	-	27-34	FT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.351(b)-§ 27.351(c)	-	27-34	FT,SC	AC 27-1B	A special condition would be requested to certify the yawing conditions that the pilotless rotorcraft may incur during maximum flight control actuations or propulsion system limits. An additional subsection (d) with performance-based airworthiness criteria would be suggested, stating, "Pilotless rotorcraft shall induce maximum yawing conditions loading through maximum certified flight control logic to certify the loads as described in § 27.351(b) and § 27.351(c) ."
§ 27.361	Engine torque.	27-23	-		Compliance is shown in subsections.
§ 27.361(a)-§ 27.361(b)	-	27-23	AN	AC 27-1B	
§ 27.391	General.	27-34	DE	AC 27-1B	
§ 27.395	Control system.	27-26	-		Compliance is shown in subparagraphs.
§ 27.395(a)	-	27-26	N/A		In-cockpit controls are not included in the notional rotorcraft.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.395(b)	-	27-26	SC	AC 27-1B	A special condition would be requested to certify that the pilotless rotorcraft control system meets requisite standards for control system loads in place of in-cockpit controls and pilot forces. The pilotless rotorcraft's control system must withstand the maximum certified flight control forces. An additional subsection (c) would be suggested, stating, "Pilotless rotorcraft control systems must withstand maximum certified loads resulting from maximum flight control forces from autonomous flight control logic."
§ 27.397	Limit pilot forces and torques.	27-40	N/A		In-cockpit controls are not included in the notional rotorcraft.
§ 27.399	Dual control system.	Initial	N/A		In-cockpit controls are not included in the notional rotorcraft.
§ 27.401	[Removed.]	27-27			
§ 27.403	[Removed.]	27-27			
§ 27.411	Ground clearance: tail rotor guard.	Initial	N/A		The notional rotorcraft does not include a tail rotor.
§ 27.413	[Removed.]	27-27			
§ 27.427	Unsymmetrical loads.	27-27	-		Compliance is shown in subsections.
§ 27.427(a)-§ 27.427(c)	-	27-27	FT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.471	General.	Initial	-		Compliance is shown in subsections.
§ 27.471(a)-§ 27.471(b)	-	Initial	FT,GT	AC 27-1B	
§ 27.473	Ground loading conditions and assumptions.	27-2	-		Compliance is shown in subsections.
§ 27.473(a)-§ 27.473(b)	-	27-2	AN,FT,GT	AC 27-1B	
§ 27.475	Tires and shock absorbers.	Initial	GT	AC 27-1B	
§ 27.477	Landing gear arrangement.	Initial	DE	AC 27-1B	
§ 27.479	Level landing conditions.	Initial	-		Compliance is shown in subsections.
§ 27.479(a)-§ 27.479(c)	-	Initial	FT	AC 27-1B	
§ 27.481	Tail-down landing conditions.	Initial	-		Compliance is shown in subsections.
§ 27.481(a)-§ 27.481(b)	-	Initial	FT	AC 27-1B	
§ 27.483	One-wheel landing conditions.	Initial	-		Compliance is shown in subsections.
§ 27.483(a)-§ 27.483(b)	-	Initial	FT	AC 27-1B	
§ 27.485	Lateral drift landing conditions.	Initial	-		Compliance is shown in subsections.
§ 27.485(a)-§ 27.485(b)	-	Initial	FT	AC 27-1B	
§ 27.493	Braked roll conditions.	Initial	-		Compliance is shown in subsections.
§ 27.493(a)-§ 27.493(b)	-	Initial	FT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.497	Ground loading conditions: landing gear with tail wheels.	Initial	N/A		Tail wheel not included in design.
§ 27.501	Ground loading conditions: landing gear with skids.	27-26	-		Compliance is shown in subparagraphs.
§ 27.501(a)-§ 27.501(f)	-	Initial	GT	AC 27-1B	
§ 27.505	Ski landing conditions.	Initial	N/A		Skis are not included in design.
§ 27.521	Float landing conditions.	Initial	N/A		Floats are not included in design.
§ 27.547	Main rotor structure.	27-3	-		Compliance is shown in subparagraphs.
§ 27.547(a)-§ 27.547(e)	-	27-3	AN,FT,GT	AC 27-1B	
§ 27.549	Fuselage, landing gear, and rotor pylon structures.	27-3	-		Compliance is shown in subparagraphs.
§ 27.549(a)-§ 27.549(d)	-	27-3	AN,GT	AC 27-1B	
§ 27.561	General.	27-32	-		Compliance is shown in subparagraphs.
§ 27.561(a)-§ 27.561(c)	-	27-32	AN	AC 27-1B	
§ 27.562	Emergency landing dynamic conditions.	27-25	-		Compliance is shown in subparagraphs.
§ 27.562(a)-§ 27.562(d)	-	27-25	AN,GT	AC 27-1B	
§ 27.563	Structural ditching provisions.	27-26	-		Compliance is shown in subparagraphs.
§ 27.563(a)-§ 27.563(b)	-	27-26	AN	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.571	Fatigue evaluation of flight structure.	27-26	-		Compliance is shown in subparagraphs.
§ 27.571(a)-§ 27.571(e)	-	27-26	FT,GT	AC 27-1B	
§ 27.573	Damage Tolerance and Fatigue Evaluation of Composite Rotorcraft Structures.	27-47	-		Compliance is shown in subparagraphs.
§ 27.573(a)-§ 27.573(e)	-	27-47	AN,GT	AC 27-1B	
Subpart D - Design and Construction					
§ 27.601	Design.	Initial	-		Compliance is shown in subsection.
§ 27.601(a)-§ 27.601(b)	-	Initial	AN,FT,GT	AC 27-1B	
§ 27.602	Critical parts.	27-38	-		Compliance is shown in subsection.
§ 27.602(a)-§ 27.602(b)	-	27-38	AN,GT	AC 27-1B	
§ 27.603	Materials.	27-16	-		Compliance is shown in subsection.
§ 27.603(a)-§ 27.603(c)	-	27-16	AN	AC 27-1B	
§ 27.605	Fabrication methods.	27-16	-		Compliance is shown in subsection.
§ 27.605(a)-§ 27.605(c)	-	27-16	AN	AC 27-1B	
§ 27.607	Fasteners.	27-4	-		Compliance is shown in subsection.
§ 27.607(a)-§ 27.607(b)	-	27-4	AN	AC 27-1B; AC20-71	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.609	Protection of structure.	Initial	-		Compliance is shown in subsection.
§ 27.609(a)-§ 27.609(b)	-	Initial	AN	AC 27-1B	
§ 27.610	Lightning and static electricity protection.	27-46	-		Compliance is shown in subsection.
§ 27.610(a)-§ 27.610(d)	-	27-46	AN,GT	AC 27-1B	
§ 27.611	Inspection provisions.	Initial	-		Compliance is shown in subsection.
§ 27.611(a)-§ 27.611(c)	-	Initial	AN,GT	AC 27-1B	
§ 27.613	Material strength properties and design values.	27-26	-		Compliance is shown in subsection.
§ 27.613(a)-§ 27.613(e)	-	27-26	AN	AC 27-1B	
§ 27.619	Special factors.	Initial	-		Compliance is shown in subsection.
§ 27.619(a)-§ 27.619(b)	-	Initial	AN	AC 27-1B; AC20-107	
§ 27.621	Casting factors.	27-34	-		Compliance is shown in subparagraphs.
§ 27.621(a)-§ 27.621(d)	-	27-34	AN	AC 27-1B	
§ 27.623	Bearing factors.	Initial	-		Compliance is shown in subsection.
§ 27.623(a)-§ 27.623(b)	-	Initial	AN	AC 27-1B	
§ 27.625	Fitting factors.	27-35	-		Compliance is shown in subsection.
§ 27.625(a)-§ 27.625(d)	-	27-35	AN	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.629	Flutter.	27-26	FT,GT	AC 27-1B	
§ 27.653	Pressure venting and drainage of rotor blades.	27-2	-		Compliance is shown in subsection.
§ 27.653(a)-§ 27.653(b)	-	27-2	DE	AC 27-1B	
§ 27.659	Mass balance.	27-2	-		Compliance is shown in subsection.
§ 27.659(a)-§ 27.659(b)	-	27-2	DE	AC 27-1B	
§ 27.661	Rotor blade clearance.	27-2	FT,GT	AC 27-1B	
§ 27.663	Ground resonance prevention means.	27-26	-		Compliance is shown in subsection.
§ 27.663(a)-§ 27.663(b)	-	27-26	AN,GT	AC 27-1B	
§ 27.671	General.	Initial	-		Compliance is shown in subsection.
§ 27.671(a)-§ 27.671(b)	-	Initial	GT,SC	AC 27-1B	A special condition would be requested to omit the requirement of "each control" in subpart (a) due to the notional rotorcraft not having onboard crew.
§ 27.672	Stability augmentation, automatic, and power-operated systems.	27-21	N/A		Compliance is shown in subsection.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.672(a)	-	27-21	SC	AC 27-1B	A special condition would be requested to show compliance that the notional rotorcraft's flight control system would send an alert to the ground station that a stability augmentation system degradation exists.
§ 27.672(b)	-	27-21	SC	AC 27-1B	A special condition would be requested to show compliance that the notional rotorcraft's flight control system will maintain stability and control during an in-flight stability augmentation system failure. Pilotless rotorcraft inherently require stability augmentation, automatic, and power-operated systems to maintain stability and control. Durability and reliability testing via flight test and computational simulation would certify the special condition by testing the flight control system with test induced failures. Zero failure tolerance is required. An additional subsection (d) would be suggested, stating, "Pilotless rotorcraft must comply with all subsections of § 27.672 where stability augmentation failures must be autonomously recognized and autonomously counteracted to maintain stability and control of the rotorcraft."

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.672(c)	-	27-21	AN,FT	AC 27-1B	
§ 27.673	Primary flight control.	27-21	N/A		In-cockpit control systems are not included in the notional rotorcraft.
§ 27.674	Interconnected controls.	27-26	N/A		In-cockpit control systems are not included in the notional rotorcraft.
§ 27.675	Stops.	27-16	N/A		In-cockpit control systems are not included in the notional rotorcraft.
§ 27.679	Control system locks.	Initial	N/A		In-cockpit control systems are not included in the notional rotorcraft.
§ 27.681	Limit load static tests.	Initial	-		Compliance is shown in subsection.
§ 27.681(a)-§ 27.681(b)	-	Initial	GT	AC 27-1B	
§ 27.683	Operation tests.	Initial	-		Compliance is shown in subsection.
§ 27.683(a)-§ 27.683(c)	-	Initial	SC	AC 27-1B	A special condition would be requested to show compliance that the multirotor reactive torque control system on the notional rotorcraft is free from jamming, excessive friction and excessive deflection. An additional subsection (d) would be suggested, stating, "Pilotless rotorcraft that do not have in-cockpit controls must have autonomous control systems that comply with § 27.683(a)-§ 27.683(c) ."

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.685	Control system details.	27-49	-		Compliance is shown in subsection.
§ 27.685(a)	-	27-49	DE	AC 27-1B	
§ 27.685(b)	-	27-49	DE	AC 27-1B	
§ 27.685(c)	-	27-49	N/A		The notional rotorcraft does not include the use of cables or tubes.
§ 27.685(d)	-	27-49	N/A		The notional rotorcraft does not include the use of cables.
§ 27.685(e)	-	27-49	N/A		The notional rotorcraft does not include the use of cables or push-pull systems.
§ 27.685(f)	-	27-49	DE	AC 27-1B	
§ 27.687	Spring devices.	Initial	N/A		Spring devices are not included in the notional rotorcraft.
§ 27.691	Autorotation control mechanism.	Initial	DE,FT	AC 27-1B	
§ 27.695	Power boost and power-operated control system.	Initial	DE,AN,GT	AC 27-1B	
§ 27.723	Shock absorption tests.	Initial	GT	AC 27-1B	
§ 27.725	Limit drop test.	Initial	-		Compliance is shown in the subsections.
§ 27.725(a)-§ 27.725(d)	-	Initial	GT	AC 27-1B	
§ 27.727	Reserve energy absorption drop test.	27-26	-		Compliance is shown in the subsections.
§ 27.727(a)-§ 27.727(c)	-	27-26	GT	AC 27-1B	
§ 27.729	Retracting mechanism.	27-21	N/A		The notional rotorcraft includes fixed landing gear without a retracting mechanism.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.731	Wheels.	Initial	-		Compliance is shown in the subsections.
§ 27.731(a)-§ 27.731(c)	-	27-21	AN	TSO-C26; AC 27-1B	
§ 27.733	Tires.	27-11	-		Compliance is shown in the subsections.
§ 27.733(a)-§ 27.733(c)	-	27-21	AN	TSO-C62; AC 27-1B	
§ 27.735	Brakes.	27-21	N/A		The notional rotorcraft does not include wheel-type landing gear requiring a braking device.
§ 27.737	Skis.	Initial	N/A		Skis are not included in the notional rotorcraft.
§ 27.751	Main float buoyancy.	27-2	N/A		Floats are not included in the notional rotorcraft.
§ 27.753	Main float design.	Initial	N/A		Floats are not included in the notional rotorcraft.
§ 27.755	Hulls.	Initial	N/A		Floats are not included in the notional rotorcraft.
§ 27.771	Pilot compartment.	Initial	N/A		The notional rotorcraft is pilotless and requires no outside visibility for operation.
§ 27.773	Pilot compartment view.	27-50	N/A		The notional rotorcraft is pilotless and requires no outside visibility for operation.
§ 27.775	Windshields and windows.	27-27	AN	MIL-G-25871; AC 27-1B	
§ 27.777	Cockpit controls.	Initial	N/A		In-cockpit controls are not included in the notional rotorcraft.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.779	Motion and effect of cockpit controls.	27-21	N/A		In-cockpit controls are not included in the notional rotorcraft.
§ 27.783	Doors.	27-26	-		Compliance is shown in subsection.
§ 27.783(a)-§ 27.783(b)	-	27-26	DE	AC 27-1B	
§ 27.785	Seats, berths, litters, safety belts, and harnesses.	27-35	-		Compliance is shown in subparagraph.
§ 27.783(a)-§ 27.783(k)	-	27-35	DE	AC 27-1B	
§ 27.783(f)(1)	-	27-35	N/A		The notional rotorcraft does not include seating for pilots.
§ 27.787	Cargo and baggage compartments.	27-27	-		Compliance is shown in subparagraphs.
§ 27.787(a)-§ 27.787(d)	-	27-27	AN,FT	AC 27-1B	
§ 27.801	Ditching.	27-11	N/A		Ditching certification is not requested due to CONOPS including only urban areas of operation.
§ 27.805	Flight crew emergency exits.	27-37	N/A		Flight crew will not be onboard the notional rotorcraft.
§ 27.807	Emergency exits.	27-37	-		Compliance is shown in subparagraphs.
§ 27.807(a)-§ 27.807(d)	-	27-37	AN,GT	AC 27-1B	
§ 27.831	Ventilation.	Initial	-		Compliance is shown in subparagraphs.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.831(a)-§ 27.831(b)	-	Initial	FT	AC 27-1B	
§ 27.833	Heaters.	27-23	GT	TSO-C20; AC 27-1B	
§ 27.853	Compartment interiors.	27-37	-		Compliance is shown in subparagraphs.
§ 27.853(a)-§ 27.853(c)	-	27-37	DE	AC 27-1B	
§ 27.855	Cargo and baggage compartments.	Initial	-		Compliance is shown in subparagraphs.
§ 27.855(a)-§ 27.855(b)	-	Initial	DE	AC23-2; AC 27-1B	
§ 27.859	Heating systems.	27-23	-		Compliance is shown in subparagraphs.
§ 27.859(a)-§ 27.859(k)	-	Initial	DE	AC20-135; AC 27-1B	
§ 27.861	Fire protection of structure, controls, and other parts.	27-26	DE	AC 27-1B	
§ 27.863	Flammable fluid fire protection.	27-16	-		Compliance is shown in subparagraphs.
§ 27.863(a)-§ 27.863(d)	-	27-16	DE	AC 27-1B	
§ 27.865	External Loads.	27-36	N/A		External loads are not included within the concept of operations of the notional rotorcraft.
§ 27.871	Leveling marks.	Initial	DE	AC 27-1B	
§ 27.873	Ballast provisions.	Initial	FT	AC 27-1B	
Subpart E - Powerplant					
§ 27.901	Installation.	27-23	-		Compliance is shown in subparagraphs.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.901(a)-§ 27.901(c)	-	27-23	AN,DE,ELOS	§ 33.5; AC 27-1B, AC 20-184	Installation of the electric powerplant and Lithium battery system can be shown with ELOS through installation guidance in AC 20-184.
§ 27.903	Engines.	27-44	-		Compliance is shown in subparagraphs.
§ 27.903(a)	Engine Type Certification.	27-44	AN,FT,GT	AC 27-1B	
§ 27.903(b)	Engine or drive system cooling fan blade protection.	27-44	AN,FT,GT	AC 27-1B	
§ 27.903(c)-§ 27.903(d)	-	27-44	N/A		The notional rotorcraft utilizes electric propulsion and does not utilize fossil fuels.
§ 27.907	Engine vibration.	Initial	-		Compliance is shown in subparagraphs.
§ 27.907(a)-§ 27.907(c)	-	Initial	AN,GT	AC 27 MG 11, FAA Order 8110.9, Part 33; AC 27-1B	
§ 27.917	Design.	27-11	-		Compliance is shown in subparagraphs.
§ 27.917(a)-§ 27.917(d)	-	27-11	GT,DE	AC 27-1B	
§ 27.921	Rotor brake.	Initial	N/A		A rotor brake is not included in the notional rotorcraft.
§ 27.923	Rotor drive system and control mechanism tests.	27-29	-		Compliance is shown in subparagraphs.
§ 27.923(a)-§ 27.923(k)	-	27-29	FT,GT	AC 27-1B	
§ 27.927	Additional tests.	27-23	-		Compliance is shown in subparagraphs.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.927(a)	-	27-23	AN,FT,GT	AC 27-1B	
§ 27.927(b)	-	27-23	N/A		The notional rotorcraft does not include a turbine power plant.
§ 27.927(c)	-	27-23	AN,FT,GT	AC 27-1B	
§ 27.931	Shafting critical speed.	Initial	-		Compliance is shown in subsections.
§ 27.931(a)-§ 27.931(c)	-	Initial	AN	AC 27-1B	
§ 27.935	Shafting joints.	Initial	N/A		The notional rotorcraft does not include any shafting joints due to the direct drive electric propulsion system.
§ 27.939	Turbine engine operating characteristics.	27-11	N/A		The notional rotorcraft does not include a turbine engine.
§ 27.951	General.	27-9	-	AC 20-184	Compliance is shown in subparagraphs. Fossil fuels are not utilized in the notional rotorcraft. A certification gap currently exists in § 27.951 for electric propulsion. Lithium batteries power the notional rotorcraft. AC20-184 provides guidance for Lithium battery airworthiness compliance.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.951(a)-§ 27.951(c)	-	27-9	SC	SC No. 33-022-SC (magniX USA) EASA Special Condition SC E-19-Electric/Hybrid Propulsion System (EHPS.380 Propulsion battery) AC 20-184	The notional rotorcraft is fully electric. A request for a special condition for fuel system certification for the Lithium battery system would be requested. An additional subsection (c) would be suggested, stating, "If an electric powerplant is powered by a electro-chemical battery, the battery and associated battery management system must be designed and built to provide requisite power to the electric powerplant to assure the rotorcraft meets performance and mission requirements." The EASA SC E-19 EHPS.380 Propulsion battery provides guidance for electric powerplant battery regulation.
§ 27.952	Fuel system crash resistance.	27-30	-		Compliance is shown in subparagraphs.
§ 27.952(a)-§ 27.952(g)	-	27-30	GT,SC	AC 27-1B	The notional rotorcraft is fully electric. A request for a special condition for the Lithium battery system's crash resistance would be requested.
§ 27.953	Fuel system independence.	Initial	SC	SC No. 33-022-SC (magniX USA)	Compliance is shown in subparagraphs.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.953(a)-§ 27.953(b)	-	Initial	SC	AC 27-1B SC No. 33-022-SC (magniX USA)	The notional rotorcraft is fully electric. A request for a special condition for fuel system certification for the Lithium battery system's independence would be requested. The magniX USA powerplant certification provides guidance for powerplant and fuel system independence. An additional subsection (c) would be suggested, stating, "If an electric powerplant is powered by a electro-chemical battery, the battery, motor controller and associated battery management system must be fully independent and allow for full engine operation with failed battery cells, failed motor controllers, or failed battery management systems."
§ 27.954	Fuel system lightning protection.	27-23	SC	SC No. 33-022-SC (magniX USA)	Compliance is shown in subparagraphs.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.954(a)-§ 27.954(c)	-	27-23	SC	AC 27-1B SC No. 33-022-SC (magniX USA)	The notional rotorcraft is fully electric. A request for a special condition for fuel system certification for the Lithium battery system's lightning protection would be requested. An additional subsection (d) would be suggested, stating, "If an electric powerplant is powered by an electro-chemical battery, the battery system must be designed and arranged to prevent ignition of the battery due to lightning strikes and lightning conditions described in § 27.954(a)-§ 27.954(b)." The magniX USA certification provides additional reference for lightning provisions for electric powerplants.
§ 27.955	Fuel flow.	27-23	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.959	Unusable fuel supply.	Initial	N/A		Fossil fuels are not utilized in the notional rotorcraft.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.961	Fuel system hot weather operation.	27-23	SC	AC 27-1B SC No. 33-022-SC (magniX USA)	The notional rotorcraft is fully electric. A request for a special condition for fuel system certification for the Lithium battery system's hot weather operation would be requested. In AC 20-184, airworthiness compliance standards for Lithium batteries are set forth and hot weather certification standards for an electric powerplant and Lithium battery system can be developed from AC 20-184 and magniX USA certification. An additional section (a) would be suggested, stating, "Rotorcraft utilizing electric power plants powered by electro-chemical batteries must meet established powerplant performance standards in hot weather conditions and degraded battery states and additional conditions set forth in § 27.927."
§ 27.963	Fuel tanks: general.	27-30	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.965	Fuel tank tests.	27-12	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.967	Fuel tank installation.	27-30	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.969	Fuel tank expansion space.	27-23	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.971	Fuel tank sump.	27-23	N/A		Fossil fuels are not utilized in the notional rotorcraft.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.973	Fuel tank filler connection.	27-30	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.975	Fuel tank vents.	27-35	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.977	Fuel tank outlet.	27-11	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.991	Fuel pumps.	27-23	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.993	Fuel system lines and fittings.	27-2	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.995	Fuel valves.	Initial	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.997	Fuel strainer or filter.	27-23	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.999	Fuel system drains.	27-23	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.1011	Engines: general.	27-23	N/A		The notional rotorcraft utilizes an electric propulsion system that does not require oil lubrication.
§ 27.1013	Oil tanks.	27-9	N/A		The notional rotorcraft utilizes an electric propulsion system that does not require oil lubrication.
§ 27.1015	Oil tank tests.	27-9	N/A		The notional rotorcraft utilizes an electric propulsion system that does not require oil lubrication.
§ 27.1017	Oil lines and fittings.	Initial	N/A		The notional rotorcraft utilizes an electric propulsion system that does not require oil lubrication.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1019	Oil strainer or filter.	27-23	N/A		The notional rotorcraft utilizes an electric propulsion system that does not require oil lubrication.
§ 27.1021	Oil system drains.	27-20	N/A		The notional rotorcraft utilizes an electric propulsion system that does not require oil lubrication.
§ 27.1027	Transmissions and gearboxes: General.	27-37	N/A		The notional rotorcraft utilizes an electric propulsion system that is direct drive and does not include a transmission or gearbox.
§ 27.1041	General.	27-23	-		Compliance is shown in subsections.
§ 27.1041(a)-§ 27.1041(b)	-	27-23	FT,GT,SC	AC 27-1B SC No. 33-022-SC (magniX USA) EASA Special Condition SC E-19-Electric/Hybrid Propulsion System (EHPS.320 Cooling system)	The notional rotorcraft is fully electric. A special condition would be requested to certify the cooling system of the electric powerplant. The magniX USA special condition certification under 14 CFR Part 33 provides guidance for electric powerplant cooling system certification.
§ 27.1043	Cooling tests.	27-14	-		Compliance is shown in subsections.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1043(a)	General.	27-14	FT,GT,SC	AC 27-1B SC No. 33-022-SC (magniX USA) SC No. 33-022-SC (magniX USA)	The notional rotorcraft is fully electric. A request for a special condition for the electric propulsion systems cooling performance would be requested. The magniX USA certification provides guidance for special conditions that are applicable to electric powerplant cooling system certification.
§ 27.1043(b)	Maximum ambient temperature.	27-14	FT,GT,SC	AC 27-1B SC No. 33-022-SC (magniX USA)	The notional rotorcraft is fully electric. A request for a special condition for the electric propulsion systems cooling performance would be requested. The magniX USA certification provides guidance for special conditions that are applicable to electric powerplant cooling system certification.
§ 27.1043(c)	Correction factor (except cylinder barrels).	27-14	FT,GT,SC	AC 27-1B SC No. 33-022-SC (magniX USA)	The notional rotorcraft is fully electric. A request for a special condition for the electric propulsion systems cooling performance would be requested.The magniX USA certification provides guidance for special conditions that are applicable to electric powerplant cooling system certification.
§ 27.1043(d)	Correction factor for cylinder barrel temperatures.	27-14	N/A		Internal combustion engines are not utilized in the notional rotorcraft.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1045	Cooling test procedures.	27-23	-		Compliance is shown in subsections.
§ 27.1045(a)-§ 27.1045(c)	-	27-23	FT	AC 27-1B	
§ 27.1091	Air induction.	27-23	N/A		Internal combustion engines are not utilized in the notional rotorcraft.
§ 27.1093	Induction system icing protection.	27-23	N/A		Internal combustion engines are not utilized in the notional rotorcraft.
§ 27.1121	General.	27-12	N/A		Internal combustion engines are not utilized in the notional rotorcraft.
§ 27.1123	Exhaust piping.	27-11	N/A		Internal combustion engines are not utilized in the notional rotorcraft.
§ 27.1141	Powerplant controls: general.	27-33	N/A		The notional rotorcraft does not include in-cockpit power plant controls.
§ 27.1143	Engine controls.	27-29	N/A		The notional rotorcraft does not include in-cockpit engine controls.
§ 27.1145	Ignition switches.	27-12	N/A		The notional rotorcraft does not include in-cockpit ignition controls.
§ 27.1147	Mixture controls.	Initial	N/A		The notional rotorcraft does not include in-cockpit mixture controls.
§ 27.1151	Rotor brake controls.	27-33	N/A		The notional rotorcraft does not include in-cockpit rotor brake controls.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1163	Powerplant accessories.	27-23	N/A		The notional rotorcraft does not include in-cockpit powerplant accessory controls.
§ 27.1183	Lines, fittings, and components.	27-20	-		Compliance is shown in subsections.
§ 27.1183(a)-§ 27.1183(c)	-	27-20	DE	AC20-135, AC23-2; AC 27-1B	
§ 27.1185	Flammable fluids.	27-37	N/A		Fossil and flammable fuels are not utilized in the notional rotorcraft.
§ 27.1187	Ventilation and drainage.	27-37	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.1189	Shutoff means.	27-23	N/A		Fossil fuels are not utilized in the notional rotorcraft.
§ 27.1191	Firewalls.	27-2	-		Compliance is shown in subsections.
§ 27.1191(a)	-	27-2	DE	AC 27-1B	
§ 27.1191(b)	-	27-2	N/A		The notional rotorcraft does not include an APU.
§ 27.1191(c)-§ 27.1191(f)	-	27-2	DE	AC 27-1B	
§ 27.1193	Cowling and engine compartment covering.	27-23	-		Compliance is shown in subsections.
§ 27.1193(a)-§ 27.1193(f)	-	27-23	DE,FT	AC 27-1B	
§ 27.1194	Other surfaces.	27-2	DE	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1195	Fire detector systems.	27-5	AN,SC	AC20-144A; AC 27-1B	A special condition would be requested as the notional pilotless rotorcraft must be able to detect and combat onboard fires. Lithium battery technology is included in the notional rotorcraft and are susceptible to fire if punctured, overcharged, exposed to high temperatures or thermal runaway during charging. Performance-based airworthiness criteria for onboard fire detecting and firefighting would be suggested in a subsection (a). Subsection (a) would state,"Pilotless rotorcraft must include autonomous fire detection, fire suppression and flight control casualty management that assures stability and control of the rotorcraft in the event of an onboard fire." AC20-144A provides guidelines for the certification of electrical firing cartridge components in rotorcraft fire extinguishing systems.
Subpart F - Equipment					
§ 27.1301	Function and installation.	Initial	-		Compliance is shown in subsections.
§ 27.1301(a)-§ 27.1301(d)	-	Initial	DE	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1303	Flight and navigation instruments.	Initial	-		Compliance is shown in subsections.
§ 27.1303(a)-§ 27.1303(c)	-	Initial	DE,SC	AC 27-1B SC No. FAA-2020-1086 (Amazon Logistics, Inc. MK27)	A special condition would be requested for the notional pilotless rotorcraft to display the required flight and navigation instruments at the ground station but not in the cockpit. An additional subsection (d) that includes performance-based airworthiness criteria would be suggested, stating, “Pilotless rotorcraft do not require in-cockpit instruments to be displayed but must transmit rotorcraft safety critical data for offboard monitoring.” The Amazon MK27 § 21.17(b) certification provides FAA guidance to what cockpit instruments must be displayed at a ground station.
§ 27.1305	Powerplant instruments.	27-37	-		Compliance is shown in subsections.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1305(a)-§ 27.1305(v)	-	27-37	N/A,SC	AC 27-1B EASA Special Condition SC E-19-Electric/Hybrid Propulsion System (EHPS.360 Aircraft instruments)	A special condition would be requested to certify the required powerplant instruments. The notional rotorcraft includes an electric propulsion system which requires powerplant instruments that monitor the status of safety critical systems such as standard electrical monitoring instruments displaying current, voltage and battery life as well as engine instruments displaying engine rpm and engine torque. An additional subsection (w) that includes performance-based airworthiness criteria would be suggested, and state, "Pilotless rotorcraft do not require in-cockpit instruments to be displayed but must transmit power plant safety critical data for offboard monitoring." The EASA SC E-19 provides guidance to what rotorcraft instruments are safety critical.
§ 27.1307	Miscellaneous equipment.	Initial	-		Compliance is shown in subsections
§ 27.1307(a)-§ 27.1307(e)	-	Initial	DE	AC 27-1B	
§ 27.1309	Equipment, systems, and installations.	27-46	-		Compliance is shown in subsections
§ 27.1309(a)-§ 27.1309(c)	-	27-46	AN,GT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1316	Electrical and electronic system lightning protection.	27-46	-		Compliance is shown in subsections
§ 27.1316(a)-§ 27.1316(b)	-	27-46	AN,GT	AC 20-136B, ED-113, ED-81; AC 27-1B	
§ 27.1317	High-Intensity Radiated Fields (HIRF) Protection	27-42	-		Compliance is shown in subsections.
§ 27.1317(a)-§ 27.1317(d)	-	27-42	AN,GT	AC 20-158, ED-107; AC 27-1B	
§ 27.1321	Arrangement and visibility.	27-13	-		Compliance is shown in subsections.
§ 27.1321(a)-§ 27.1321(d)	-	27-13	N/A,SC	AC 27-1B EASA Special Condition SC E-19-Electric/Hybrid Propulsion System (EHPS.360 Aircraft instruments)	The notional rotorcraft is pilotless and a special condition would be requested to not display any instruments in the cockpit. An additional subsection (e) that includes performance-based airworthiness criteria would be suggested, stating, "Pilotless rotorcraft do not require in-cockpit instruments to be displayed but must transmit safety critical data for offboard monitoring." The EASA SC E-19 provides guidance to what rotorcraft instruments are safety critical.
§ 27.1322	Warning, caution, and advisory lights.	27-11	-		Compliance is shown in subsections.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1322(a)-§ 27.1322(d)	-	27-11	N/A		The notional rotorcraft will not display any warning, caution, or advisory lights in the cockpit.
§ 27.1323	Airspeed indicating system.	27-13	-		Compliance is shown in subsections.
§ 27.1323(a)-§ 27.1323(c)	-	27-13	FT	TSO C16; AC 27-1B	
§ 27.1325	Static pressure systems.	27-13	-		Compliance is shown in subsections.
§ 27.1325(a)-§ 27.1325(d)	-	27-13	FT	TSO C16; AC 27-1B	
§ 27.1327	Magnetic direction indicator.	27-13	-		Compliance is shown in subsections.
§ 27.1327(a)-§ 27.1327(b)	-	27-13	FT,GT	TSO-C7c, RTCA DO 160B; AC 27-1B	
§ 27.1329	Automatic pilot system.	27-35	-		Compliance is shown in subsections.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1329(a)-§ 27.1329(f)	-	27-35	N/A,SC	AC 27-1B	A special condition would be requested as the notional rotorcraft relies on automation to maintain stability and control. Fully autonomous, pilotless rotorcraft must include flight control logic that can safely manage inflight casualties, flight path avoidance and other safety of flight critical emergencies. Fully autonomous flight control systems do not include manual handoff to a human operator. An additional subsection (g) would be suggested, stating, “Pilotless rotorcraft must have a certified flight control computer that substitutes certified pilot skill to maintain complete autonomy throughout operation and shall not exceed certified computational, flight control, structural, or propulsion limits to maintain safety of flight.” The requested special condition would be certified through durability and reliability testing via flight test and computational simulation where zero failure tolerance is required.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1335	Flight director systems.	27-13	N/A,SC	AC 27-1B Karr, D. A., Wing, D. J., Barney, T., Sharma, V., Etherington, T. J., & Sturdy, J. L. (2021). Initial design guidelines for onboard automation of Flight Path Management. *AIAA Aviation 2021 Forum*. https://doi.org/10.2514/6.2021-2326	A special condition would be requested as the notional pilotless rotorcraft's automatic pilot system works in conjunction with the flight director system to fly the pre-programmed route. Flight path detection and avoidance technologies must be incorporated to assure safety of flight. An additional subsection (a) would be suggested, stating, "Pilotless rotorcraft must have a certified flight control computer that substitutes certified pilot skill and judgment to maintain complete autonomy throughout operation and shall not exceed certified computational, flight control, structural, or propulsion limits to maintain safe routing or safety of flight." The requested special condition would be certified through durability and reliability testing via flight test and computational simulation where zero failure tolerance is required. Guidance for automated detect-and-avoid technology is included in the associated reference.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1337	Powerplant instruments.	27-37	N/A		The notional rotorcraft will not display any instruments in the cockpit therefore precluding any in-cockpit instrument installation requirements. Telemetry data will be transmitted to a ground station which will display the instruments for offboard monitoring.
§ 27.1351	General.	27-13	-		Compliance is shown in subsections.
§ 27.1351(a)-§ 27.1351(e)	-	27-13	AN,DE,GT	AC 27-1B	
§ 27.1353	Storage battery design and installation.	27-14	-		Compliance is shown in subsections.
§ 27.1353(a)-§ 27.1353(e)	-	27-14	AN,DE,GT	AC 27-1B	
§ 27.1353(f)-§ 27.1353(g)	-	27-14	N/A		The notional rotorcraft does not carry nickel cadmium batteries to start an engine or APU.
§ 27.1357	Circuit protective devices.	27-13	-		Compliance is shown in subsections.
§ 27.1357(a)-§ 27.1357(e)	-	27-13	DE,FT,GT,SC	AC 27-1B	A special condition will be requested as the pilotless rotorcraft will require an autonomous electrical management system that is capable of identifying circuit faults and autonomously resetting fuses that are tripped.
§ 27.1361	Master switch.	Initial	N/A		The notional rotorcraft does not include in-cockpit switches.
§ 27.1365	Electric cables.	27-35	-		Compliance is shown in subsections.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1365(a)-§ 27.1365(c)	-	27-35	AN	MIL-W-81381A; AC 27-1B	
§ 27.1367	Switches.	Initial	N/A		The notional rotorcraft does not include in-cockpit switches.
§ 27.1381	Instrument lights.	Initial	N/A		The notional rotorcraft does not include in-cockpit instruments.
§ 27.1383	Landing lights.	Initial	-		Compliance is shown in subsections.
§ 27.1383(a)-§ 27.1383(c)	-	Initial	FT,GT	AC 27-1B	
§ 27.1385	Position light system installation.	Initial	-		Compliance is shown in subsections.
§ 27.1385(a)-§ 27.1385(e)	-	Initial	FT,GT	AC 27-1B; AC 20-74	
§ 27.1387	Position light system dihedral angles.	27-7	-		Compliance is shown in subsections.
§ 27.1387(a)-§ 27.1387(e)	-	27-7	FT,GT	AC 20-74; AC 27-1B	
§ 27.1389	Position light distribution and intensities.	Initial	-		Compliance is shown in subsections.
§ 27.1389(a)-§ 27.1389(b)	-	Initial	FT,GT	AC 20-74; AC 27-1B	
§ 27.1391	Minimum intensities in the horizontal plane of forward and rear position lights.	Initial	AN	AC 20-74; AC 27-1B	
§ 27.1393	Minimum intensities in any vertical plane of forward and rear position lights.	Initial	AN	AC 20-74; AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1395	Maximum intensities in overlapping beams of forward and rear position lights.	Initial	-		Compliance is shown in subsections.
§ 27.1395(a)-§ 27.1395(b)	-	Initial	DE	AC20-74; AC 27-1B	
§ 27.1397	Color specifications.	27-6	-		Compliance is shown in subsections.
§ 27.1397(a)-§ 27.1397(c)	-	27-6	AN	AC20-74; AC 27-1B	
§ 27.1399	Riding light.	27-2	N/A		The notional rotorcraft CONOP does not include amphibious operations.
§ 27.1401	Anticollision light system.	27-10	-		Compliance is shown in subsections.
§ 27.1401(a)-§ 27.1401(e)	-	27-10	DE,FT	AC20-30B, AC20-74; AC 27-1B	
§ 27.1411	General.	27-11	-		Compliance is shown in subsections.
§ 27.1411(a)-§ 27.1411(b)	-	27-11	DE	AC 27-1B	
§ 27.1413	Safety belts.	27-21	DE	TSO-C22, TSO-C114; AC 27-1B	
§ 27.1415	Ditching equipment.	27-11	N/A		The notional rotorcraft CONOP does not include operation over water.
§ 27.1419	Ice protection.	27-19	N/A		The notional rotorcraft CONOP does not include operation in known icing.
§ 27.1435	Hydraulic systems.	Initial	N/A		The notional rotorcraft does not include a hydraulic system.
§ 27.1457	Cockpit voice recorders.	27-45	-		Compliance is shown in subsections.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1457(a)-§ 27.1457(h)	-	27-45	DE,GT	TSO C84, TSO C123; AC 27-1B	
§ 27.1459	Flight recorders.	27-45	-		Compliance is shown in subsections.
§ 27.1459(a)-§ 27.1459(e)	-	27-45		TSO C124, TSO C121; AC 27-1B	
§ 27.1461	Equipment containing high energy rotors.	27-2	-		Compliance is shown in subsections.
§ 27.1461(a)-§ 27.1461(d)	-	27-2	AN,GT	AC 27-1B	
Subpart G - Operating Limitations and Information					
§ 27.1501	General.	27-14	-		Compliance is shown in subsections.
§ 27.1501(a)-§ 27.1501(b)	-	27-14	DE	AC 27-1B	
§ 27.1503	Airspeed limitations: general.	Initial	-		Compliance is shown in subsections.
§ 27.1503(a)-§ 27.1503(b)	-	Initial	AN,FT	AC 27-1B	
§ 27.1505	Never-exceed speed.	27-21	-		Compliance is shown in subsections.
§ 27.1505(a)-§ 27.1505(c)	-	27-21	AN	AC 27-1B	
§ 27.1509	Rotor speed.	Initial	-		Compliance is shown in subsections.
§ 27.1509(a)-§ 27.1509(c)	-	Initial	AN,GT	AC 27-1B	
§ 27.1519	Weight and center of gravity.	27-21	AN,FT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1521	Powerplant limitations.	27-29	-		Compliance is shown in subsections.
§ 27.1521(a)-§ 27.1521(k)	-	27-29	AN,FT,GT	14 CFR Part 33; AC 27-1B	
§ 27.1523	Minimum flight crew.	Initial	-		Compliance is shown in subsections.
§ 27.1523(a)-§ 27.1523(c)	-	Initial	AN,DE,SC	NHTSA. *Automated vehicles for safety.* SAE Standard J3016. AC 27-1B	A special condition must be requested as the notional pilotless rotorcraft has no onboard crew required for operation. All decision making is made with "human-out-of-the-loop" technology and only initialization of the notional rotorcraft requires human interaction. This airworthiness standard is typically subjective based on pilot workload, types of operations, etc. An amendment to the current regulation would include an additional subsection (d) that states,"Fully autonomous, pilotless rotorcraft require no flight crew onboard given compliance with § 27.1329 and have equivalent levels of safe autonomy to that of SAE International or NHTSA Level 5 Autonomy."
§ 27.1525	Kinds of operation.	27-21	DE	AC 27-1B	
§ 27.1527	Maximum operating altitude.	27-14	AN,FT	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1529	Instructions for Continued Airworthiness.	27-18	AN,FT	AC 27-1B	
§ 27.1541	General.	Initial	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.
§ 27.1543	Instrument markings: general.	Initial	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.
§ 27.1545	Airspeed indicator.	27-16	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.
§ 27.1547	Magnetic direction indicator.	27-13	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.
§ 27.1549	Powerplant instruments.	27-29	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.
§ 27.1551	Oil quantity indicator.	Initial	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1553	Fuel quantity indicator.	Initial	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.
§ 27.1555	Control markings.	27-21	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.
§ 27.1557	Miscellaneous markings and placards.	27-11	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.
§ 27.1559	Limitations placard.	27-21	N/A		The notional pilotless rotorcraft does not have onboard flight crew that operate the rotorcraft. This alleviates the requirement for any onboard markings.
§ 27.1561	Safety equipment.	Initial	-		Compliance is shown in subsections.
§ 27.1561(a)	-	Initial	N/A		The notional rotorcraft lacks an onboard crew therefore eliminating this requirement.
§ 27.1561(b)	-	Initial	DE	AC 27-1B	
§ 27.1565	Tail rotor.	27-2	N/A		The notional rotorcraft does not have a tail rotor.
§ 27.1581	General.	27-14	-		Compliance is shown in subsections.
§ 27.1581(a)-§ 27.1581(d)	-	27-14	DE	AC 27-1B	
§ 27.1583	Operating limitations.	27-16	-		Compliance is shown in subsections.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ 27.1583(a)-§ 27.1583(g)	-	27-16	DE	AC 27-1B	
§ 27.1585	Operating Procedures.	27-21	-		Compliance is shown in subsections.
§ 27.1585(a)-§ 27.1585(g)	-	27-21	DE	AC 27-1B	
§ 27.1587	Performance information.	27-44	-		Compliance is shown in subsections.
§ 27.1587(a)-§ 27.1587(b)	-	27-44	DE	AC 27-1B	
§ 27.1589	Loading information.	Initial	DE	AC 27-1B	
§ A27	Instructions for Continued Airworthiness	27-47	-		Compliance is shown in subsections.
§ A27.1	General.	27-18	DE	AC 27-1B	
§ A27.2	Format.	27-18	DE	AC 27-1B	
§ A27.3	Content.	27-18	DE	AC 27-1B	
§ A27.4	Airworthiness Limitations section.	27-47	DE	AC 27-1B	
§ B27	Airworthiness Criteria for Helicopter Instrument Flight	27-46	-		Compliance is shown in subsections.
§ B27.1	General.	27-19	DE	AC 27-1B	
§ B27.2	Definitions.	27-19	DE	AC 27-1B	
§ B27.3	Trim.	27-19	DE	AC 27-1B	

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ B27.4	Static longitudinal stability.	27-19	FT,SC	AC 27-1B	Pilotless rotorcraft must comply with single-pilot compliance standards where reactive propulsive forces substitute control forces. No single reactive propulsor may exceed certified limitations to maintain stability. Special conditions must be requested to certify the flight control stabilization system. An additional subsection (d) would be suggested, stating, "Pilotless rotorcraft must have a certified computationally equivalent flight control computer that would substitute certified pilot skill and shall not exceed certified computational, flight control, structural, or propulsion limits to maintain static longitudinal stability." The requested special condition would be certified through durability and reliability testing via flight test and computational simulation where zero failure tolerance is required.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ B27.5	Static lateral-directional stability.	27-44	FT,SC	AC 27-1B	Pilotless rotorcraft must comply with single-pilot compliance standards where reactive propulsive forces substitute control forces. No single reactive propulsor may exceed certified limitations to maintain stability. A special condition would be requested to certify the flight control stabilization system. An additional subsection (c) would be suggested, stating, "Pilotless rotorcraft must have a certified computationally equivalent flight control computer that would substitute certified pilot skill and shall not exceed certified computational, flight control, structural, or propulsion limits to maintain static lateral-directional stability." The requested special condition would be certified through durability and reliability testing via flight test and computational simulation where zero failure tolerance is required.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ B27.6	Dynamic stability.	27-19	FT,SC	AC 27-1B	Pilotless rotorcraft must comply with single-pilot compliance standards where reactive propulsive forces substitute control forces. No single reactive propulsor may exceed certified limitations to maintain stability. A special condition would be requested to certify the flight control stabilization system. An additional subsection (c) would be suggested, stating, "Pilotless rotorcraft must have a certified computationally equivalent flight control computer that would substitute certified pilot skill and shall not exceed certified computational, flight control, structural, or propulsion limits to maintain dynamic stability." The requested special condition would be certified through durability and reliability testing via flight test and computational simulation where zero failure tolerance is required.
§ B27.7	Stability augmentation system (SAS).	27-44	FT,SC	AC 27-1B	A special condition would be requested to certify the SAS and flight control stabilization system. SAS is inherently included in the flight control system and would be certified through its successful certification.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ B27.8	Equipment, systems, and installation.	27-19	DE,SC	SC No. FAA-2020-1086 (Amazon Logistics, Inc. MK27) SC No. FAA-2018-0379 (Yamaha Fazer R) AC 27-1B	The notional rotorcraft has no onboard crew to display instruments to but will provide telemetry data to a ground station for ground crew to view. A special condition would be requested for necessary telemetry data to be transmitted to a ground station and for initializing launch and recovery of the rotorcraft. In-flight telemetry would only be required for rotorcraft status and flight status updates. An additional subsection (c) that includes performance-based airworthiness criteria would be suggested, stating, "Pilotless rotorcraft do not require in-cockpit instruments to be displayed but must transmit rotorcraft safety critical data for offboard monitoring." The Amazon MK27 § 21.17(b) certification provides guidance to what cockpit instruments must be displayed at a ground station.
§ B27.9	Rotorcraft Flight Manual.	27-19	DE	AC 27-1B	
§ C27	Criteria for Category A	27-33	N/A		The notional rotorcraft is not seeking certification as a Category A Rotorcraft.
§ D27	HIRF Environments and Equipment HIRF Test Levels	27-42	-		Compliance is shown in subsections.

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Regulation Title 14 CFR	Section Name	Amendment	Method of Compliance*	Applicable Reference/Guidance	Remarks/Justification
§ D27(a)-§ D27(f)	-	27-42	AN,GT	AC 27-1B	

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