Designation: F3478 – 20

Standard Practice for Development of a Durability and Reliability Flight Demonstration Program for Low-Risk Unmanned Aircraft Systems (UAS) under FAA Oversight[1]

This standard is issued under the fixed designation F3478; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard practice is intended for low-risk UAS seeking type certification by the Federal Aviation Administration (FAA) under 14 CFR Part 21.17(b) in accordance with the FAA durability and reliability (D&R) means of compliance (MOC). The definition of "low-risk UAS" does not necessarily align with other definitions found within corresponding ASTM standards (F3442/F3442M) or other UAS-related standards. For the purposes of this practice, "low-risk" is defined as a UAS operated in accordance with the concept of operations (CONOPs), eligibility criteria, and kinetic energy threshold specified in the G-1 Issue Paper (which will be provided to the applicant by the FAA). See 4.3 for design criteria and operating limitations for low-risk UAS.

1.2 This standard practice establishes a common methodology and key considerations for the development of minimum flight plans for low-risk UAS that demonstrate aircraft reliability as part of a D&R MOC.

1.3 The scope of this standard practice encompasses D&R planning, data collection, and reporting.

1.4 The values stated in SI units are to be regarded as standard. This is not intended to limit the systems of units used for design, development testing, or demonstration testing. However, the units of measurement used on pilot-facing placards and markings and manuals must be the same as those used on the corresponding equipment with recognition that international aviation utilizes feet for altitude and knots for airspeed as operational parameters.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F2908 Specification for Unmanned Aircraft Flight Manual (UFM) for an Unmanned Aircraft System (UAS)
F2909 Specification for Continued Airworthiness of Lightweight Unmanned Aircraft Systems
F3060 Terminology for Aircraft
F3298 Specification for Design, Construction, and Verification of Lightweight Unmanned Aircraft Systems (UAS)
F3341/F3341M Terminology for Unmanned Aircraft Systems
F3442/F3442M Specification for Detect and Avoid System Performance Requirements

2.2 *FAA Documents:*[3]

FAA D&R MOC dated 2020-02-28 (Available from the FAA to D&R applicants)
FAA Order 8110.54A Instructions for Continued Airworthiness Responsibilities, Requirements, and Contents

3. Terminology

3.1 *Definitions*—See Terminology F3341/F3341M and Terminology F3060 for more definitions and abbreviations.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *low-risk UA, n*—an unmanned aircraft with a kinetic energy of ≤25 000 ft-lb. This includes everything that is on board or otherwise attached to the aircraft at maximum gross weight.

[1] This practice is under the jurisdiction of ASTM Committee F38 on Unmanned Aircraft Systems and is the direct responsibility of Subcommittee F38.01 on Airworthiness.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Federal Aviation Administration (FAA), 800 Independence Ave., SW, Washington, DC 20591, http://www.faa.gov.

3.2.1.1 *Discussion*—The definition of "low-risk" is unique to the D&R MOC and not intended to be used outside of this context.

3.2.2 *manual control, n*—a mode of real-time control of an unmanned aircraft where the remote pilot initiates changes and manipulates the flight controls using the UAS interface.

3.3 *Abbreviations and Acronyms:*

3.3.1 *CS*—control station

3.3.2 *D&R*—durability and reliability

3.3.3 *ICA*—instructions for continued airworthiness

3.3.4 *RSSI*—received signal strength indicator

3.3.5 *UFM*—UAS flight manual

3.3.6 *UMM*—UAS maintenance manual

4. Significance and Use

4.1 Demonstration plans developed in accordance with this practice will include all necessary content and key considerations to support an effective flight demonstration program aimed at approval or certification of UAS by the FAA through D&R demonstration.

4.2 This practice does not address planning requirements for UAS development testing. It is assumed that a manufacturer has completed all UAS design and development and is preparing demonstration programs to support compliance demonstration on a stable and controlled system configuration. Manufacturers who wish to prepare a detailed design and development program should review Specification F3298 for programmatic examples.

4.3 This practice is intended to be used on low-risk UAS that meet the following design criteria and operating limitations.

4.3.1 The UAS has a command and control link that enables the pilot-in-command to take contingency action.

4.3.2 The unmanned aircraft (UA) has a kinetic energy of ≤25 000 ft-lb calculated in accordance with methods specified within the MOC.

4.3.3 The UA is operated ≤400 ft above ground level (AGL).

4.3.4 No operations over open-air assemblies (operations over people are acceptable).

4.3.5 No flight into known icing.

4.3.6 Maximum of 20:1 aircraft to pilot ratio.

4.3.7 The UA is electrically powered (excludes internal combustion engines and fuel cells).

5. Demonstration Prerequisites

5.1 The system shall be under configuration control with established change management processes and a stable and released system configuration, inclusive of hardware and software.

5.2 Each demonstration article shall conform to the controlled system configuration(s).

5.3 A minimum of three demonstration articles (UA) shall be utilized for the D&R demonstration.

5.4 A released and controlled UFM developed in accordance with Specification F2908 shall be available. The UFM defines operations procedures, operations checklists, and operating limitations of the UAS. The demonstration operations shall follow the UFM in order to prove it is sufficient for a qualified user to safely operate the system.

5.5 A released and controlled ICA developed in accordance with Specification F2909 and FAA Order 8110.54A shall be available to maintain the UAS in a condition for safe operation during demonstration. ICA are commonly included as part of a UMM that defines maintenance procedures, inspection checklists, and life limits of components within the UAS. Any maintenance, repairs, or alteration operations completed during D&R demonstrations shall be in accordance with the ICA and UMM in order to prove it is sufficient for a qualified user to safely maintain the system.

5.6 *Demonstration Program Documentation General Requirements:*

5.6.1 A demonstration program shall involve the development of at least three documents:

5.6.1.1 Demonstration Plan.

5.6.1.2 Data Collection; Minimum Demonstration Card Information.

5.6.1.3 Demonstration Program Final Report.

5.6.2 The documentation shall be structured to include the sections and items given in Section 6. Plans shall include the content of 6.1, data collection shall include the content of 6.2, and reports shall include the content of 6.3.

5.6.2.1 The sequencing of sections may be adjusted, as needed, for documentation efficiency and flow.

5.6.2.2 Additional sections also may be included, or sections may be combined, as needed.

5.6.2.3 Minor adjustments to the section titles are acceptable to accommodate language and localization concerns and company best practices.

5.6.3 The documentation content shall be developed in accordance with the requirements, recommendations, and guidance of subsequent sections of this practice having the same titles as given in Section 6.

6. Documentation Structure

6.1 Demonstration Plan (Section 8).

6.1.1 Front Matter (Section 7).

6.1.2 Demonstration Setup (8.1).

6.1.3 Data Collection and Storage (8.2).

6.1.3.1 Demonstration Specific Hardware, Software, and Demonstration Equipment.

6.1.4 Instrumentation (8.3).

6.1.5 Data Analysis (8.4).

6.1.6 Demonstration Evaluation Criteria (8.5).

6.1.7 Demonstration Limitations (8.6).

6.1.8 Demonstration Environment (8.7).

6.1.9 Demonstration Resources (8.8).

6.1.10 Demonstration Hazard Analysis (8.9).

6.1.11 Demonstration Cases (8.10).

6.1.12 Demonstration Matrix (8.11).

6.1.13 Demonstration Procedures (8.12).

6.2 Data Collection; Minimum Demonstration Data Content

6.2.1 Front Matter (Section 7).

6.2.2 Flight Demonstration Parameters (9.1).

6.2.3 Environmental Data Content (9.2).

6.2.4 System Performance Data Content (in accordance with Demonstration) (9.3).

6.2.5 Demonstration Card Review (9.4).

6.3 Demonstration Program Final Reporting (Section 10).

6.3.1 Front Matter (Section 7).

6.3.2 Overall Demonstration Results (10.2.2)

6.3.3 General Objectives (10.2.3).

6.3.4 Specific Objectives (10.2.4)

6.3.4.1 D&R Demonstration (10.2.4.1)

6.3.4.2 Likely Failure Demonstrations (10.2.4.2).

6.3.5 Final Data Products (and data reduction processing methodology) (10.2.5).

6.3.6 Documentation of Resulting Changes (10.2.6).

6.3.7 References (10.2.7).

6.3.7.1 UFM.

6.3.7.2 Maintenance Manual.

6.3.7.3 Data Collection Forms.

7. Front Matter

7.1 *Title Page:*

7.1.1 This provides identification and tracking of the document and includes the following information:

7.1.1.1 *Documentation Title*—This should be updated to reflect whether this is a Planning Document, Data Collection, or Final Report.

7.1.1.2 Document unique identification number

7.1.1.3 Revision designation

7.1.1.4 Release date

7.1.1.5 Release authority

7.2 *Record of Revisions*—This subsection provides a listing of the document revision history and a brief synopsis of the changes.

7.3 *Purpose*—The purpose is a brief description of the intent of the documentation. It should include the UAS model identification and a high-level description of the requirements that the document that follows is intending to satisfy.

7.4 *External References*—External references should be included to identify any plans, regulations, configuration information, or other relevant documents affecting or referenced by the document.

7.5 *General*—Include an introduction and any information to appropriately set the context for the document.

7.6 *Demonstration Articles and Conformity:*

7.6.1 Identify the demonstration articles and their released configuration. Generally, this is done by reference to a released product structure or parts list that provides the product definition.

7.6.2 Identify the quantity of demonstration articles being utilized by serial number. The minimum acceptable quantity is three, in accordance with 5.3.

7.6.3 Describe the conformity status of the demonstration articles and include a reference to (or embed) a statement of conformity signed by an authorized company official. Highlight any deviations from full conformity to the intended design definition and the substantiation for the acceptability of each deviation.

7.6.4 Identify the airworthiness of the demonstration articles and under what operating rules the demonstrations are conducted; for example, Experimental R&D, Part 107 waivers, etc.

7.6.5 Describe in the planning the methodology utilized to ensure that the UAS will maintain a static configuration throughout the demonstration process. Describe in the reporting how the UAS did maintain a static configuration throughout the demonstration process.

8. Demonstration Planning

8.1 *Demonstration Setup*—Each unique demonstration type shall have a demonstration setup description that addresses the following aspects:

8.1.1 Equipment to be used.

8.1.2 Flight mission.

8.1.3 Airspace and environment.

8.1.4 Overall approach description.

8.1.5 Flight envelope.

8.2 *Data Collection and Storage:*

8.2.1 *Demonstration Specific Hardware, Software, and Demonstration Equipment:*

8.2.1.1 Identify any unique hardware, software, or equipment that is included in the demonstration or used by the UAS that differs from the released system configuration.

8.2.1.2 Include an assessment of these items and rationale for why the demonstration is still valid with their inclusion.

8.2.2 Describe how data will be collected, tagged, organized, recorded, formatted, transferred, and stored.

8.2.3 Establish media requirements for data collection, and review adequacy of media for type, amount, size, duration, bandwidth, etc. of data to be collected and stored.

8.2.4 Describe media requirements in terms resources (what kind of system, recorder, station, monitor), data collected (what kind of data, what parameters), and data/media quantity and type (file size, storage media, etc.).

8.2.5 Environmental data should be gathered in accordance with Appendix X3.

8.2.6 Other sections of this practice may specify additional data collection requirements.

8.3 *Instrumentation:*

8.3.1 Describe all instrumentation that is being utilized for data collection purposes that will support compliance determination.

8.3.2 List the parameters to be collected and recorded. Describe the parameter name, number, location, range, units, resolution, accuracy, sample rate, and any other relevant remarks, in accordance with Appendix X3.

8.3.3 Consideration should be given to the instrument accuracy, tolerances, and any calibrations to be performed to ensure adequate and reliable data.

8.4 *Data Analysis:*

8.4.1 Describe the data analysis methodology, procedures, calculations, and algorithms that will be used to show if demonstration program objectives have been met.

8.4.2 Refer to FAA D&R MOC measures of performance (MOPs) where appropriate when discussing how each MOP will be determined or demonstrated.

8.5 *Demonstration Evaluation Criteria:*

8.5.1 *D&R Demonstration*—The FAA dictates a successful demonstration when there were no failures or degradations that resulted in a UA loss of flight, loss of control, loss of containment (appreciable flight path or operational area excursion), or emergency landing outside the operator's designated recovery zone.

8.5.2 *Likely Failure and Specific Demonstrations*—The FAA dictates a successful demonstration when there were no failures that resulted in a loss of control or a loss of containment.

8.5.3 All anomalous occurrences and in-flight failures shall be documented.

8.5.4 The documentation of anomalous occurrences and in-flight failures should utilize the form template in Appendix X4, or the applicant's equivalent method.

8.6 *Demonstration Limitations:*

8.6.1 Define all applicable demonstration limitations as appropriate to the demonstration conditions. Do not simply include flight manual or other published limitations contained elsewhere. Pertinent limitations may relate to the system under demonstration, demonstration instrumentation, demonstration facilities, demonstration vehicles, or weather.

8.6.2 Demonstration limitations should discuss the differences between the actual executed demonstration and an ideal or perfect demonstration.

8.7 *Demonstration Environment:*

8.7.1 Briefly describe the location(s), time(s) of day, weather, and radio frequency conditions required for the demonstrations.

8.7.2 Describe the operating area and how the aircraft will be maintained within the established operating area during launch, mission flight, and recovery operations.

8.8 *Demonstration Resources:*

8.8.1 List all resources required to conduct the mission (for example, aircraft, ranges, hardware, software, facilities, personnel, etc.).

8.8.2 List all resources required to transmit, record, or display demonstration data.

8.8.3 Indicate that the operation of the UAS will be performed by a remote pilot in command (RPIC) and indicate any supporting crewmembers.

8.9 *Demonstration Hazard Analysis:*

8.9.1 Proper planning is an important element of keeping hazards within acceptable limits.

8.9.2 Describe all appropriate safety requirements, reviews, and documentation. Specific safety considerations should be included as appropriate, such as configuration restrictions, performance restrictions, airspace restrictions, C2 restrictions, RF restrictions, risk assessments, mitigating conditions, and mishap plans. D&R demonstration is meant to demonstrate that the range of proposed operations within the published limits/envelope can be conducted safely and reliably.

8.10 *Demonstration Cases:*

8.10.1 Demonstration cases define specific flight conditions that the UAS may experience in service. A "flight" is defined by the length of time in which the UA is airborne. A "demonstration" also may include operations before and after the flight. Each demonstration case should be tracked by a designator, such as "DC123," that can be referenced in demonstration cards, data collection, and reports to demonstrate compliance. A set of demonstration cases for all of the MOC requirements is provided in Annex A1 – Annex A3.

8.10.2 The mission details should be documented in a set of flight demonstration cards. Flight demonstration cards outline a specific sequence of events in a logical, efficient, and safe manner in which to conduct the demonstration.

8.10.3 Demonstrations shall track the duration that the UA is airborne, to include start and end times.

8.10.4 Demonstrations shall track when D&R operations are being conducted, to include start and end times.

8.10.5 Each demonstration card should be kept clear, concise, and understandable so as not to cause confusion during the mission. The individuals conducting the demonstration should, while using the demonstration cards, be able to direct the progression of the mission and ensure that all associated demonstration team members remain aligned through each step. Review of the final approved demonstration cards should occur at a pre-mission brief.

8.10.6 Demonstration case definitions may consider system configurations as well as operational scenarios.

8.10.7 Operational scenarios shall demonstrate different capabilities and considerations for the system based upon operational use; for example, if a system is intended to deliver packages, the demonstration program must demonstrate this use case.

8.10.8 Some demonstration cases in Annex A1 – Annex A3 are specific to representative operations and are a guide as to which are appropriate. See, for example, Table 1.

8.10.9 In addition, these operational scenarios should be considered (as applicable):

8.10.9.1 *Control Limits*—Exercise max control limits.

8.10.9.2 *Delivery*—Cargo release, where applicable.

8.10.9.3 *Obstacle Avoidance*—Towers, long linear infrastructure.

8.10.9.4 *Airspace*—Geofence walls, ceiling, and floor.

8.10.9.5 *Altitude Hold*—AGL, MSL, etc.

8.10.9.6 *Off-Nominal*—Lost link.

8.11 *Demonstration Matrix:*

8.11.1 The demonstration matrix summarizes the demonstration cases that will be flown, and any parameters and resources surrounding those demonstration cases. For D&R demonstrations, one parameter that shall be included is a measure of time required or a mission duration required.

8.11.2 The demonstration matrix is best presented in a tabular format with columnar headings of specific information pertinent to the demonstration. Example demonstration matrices are included in Appendix X6.

TABLE 1 Sample Representative Demonstrations

Operation	Sample Characteristic Task Element	Sample Representative Demonstration	Sample Demonstration Case Designators (see Annex A1)
Delivery	Carrying and dropping cargo	Demonstrate ability to quickly drop cargo if it interferes with safe operations	DC2, DC12, DC32
Multivehicle	Aircraft:pilot ratio of >1	Demonstrate both a nominal mission with full specified aircraft:pilot ratio and a failure injection scenario at full specified aircraft:pilot ratio where pilot in command (PIC) is required to take over manual control of one aircraft while at least one other enters an automated fail-safe mode	DC10, DC21
Beyond visual line of sight (BVLOS)	Transfer of aircraft from one CS and PIC to another	Demonstrate handoff from one CS to another without loss or duplication of control	DC31

8.12 *Demonstration Procedures:*

8.12.1 *Pre-Demonstration Briefing/Demonstration Readiness Review*—Describe who will attend and what will be addressed. Typical topics are demonstration system checkout, instrumentation checkout, ground station checkout, configuration, demonstration review, schedule, coordination, security, safety, success criteria, go/no-go criteria, real-time data requirements, and reporting data requirements.

8.12.2 *Demonstration Execution*—Identify positions to be manned and the use of demonstration information sheets or demonstration cards. Detailed demonstration execution procedures shall be documented for each flight demonstration objective, if demonstration information sheets or cards will not be used.

8.12.3 *Demonstration Documentation*—Develop a method to document whether demonstration outcomes meet the criteria for a successful demonstration in accordance with the D&R MOC.

8.12.4 *In-Process Review*—The applicant shall plan to review demonstration data at regular cadence during the demonstration program to ensure that demonstration objectives have been met. If demonstration program objectives have not been met, the applicant shall review the demonstration program and propose adjustments to meet specified objectives.

8.12.5 Review and adjust demonstration cards as required to meet stated demonstration objectives and introduce new cards as necessary.

8.12.6 Review environmental data against demonstration objectives and proposed operating limits.

9. Data Collection; Minimum Demonstration Data Content

9.1 *Flight Demonstration Parameters:*

9.1.1 If flight demonstration cards are used, they should contain the following minimum information, as applicable:

9.1.1.1 Aircraft configuration with weight and center of gravity (CG), as applicable.

9.1.1.2 Aircraft operating limits critical to the demonstration point.

9.1.1.3 Demonstration limits.

9.1.1.4 Initial conditions for start of demonstration.

9.1.1.5 Allowable data tolerances.

9.1.1.6 Maneuver parameters with associated abort, terminate, or knock-it-off tolerances, or combinations thereof, may have additional requirements on the demonstration cards.

9.1.1.7 Maximum terrain height in demonstration area if altitude not listed in AGL.

9.1.1.8 Any other maneuver parameter and associated tolerance needed.

9.1.1.9 Maneuver recovery procedure(s) that include(s) applicable tolerances.

9.1.1.10 Data acquisition system settings.

9.1.1.11 Go or no-go criteria.

9.1.1.12 Demonstration card number.

9.1.2 See Appendix X1 – Appendix X5 for examples of flight demonstration card formats.

9.2 *Environmental Data Content:*

9.2.1 Sources of weather information shall be from the U.S. National Weather Service, or a source approved by the U.S. National Weather Service; for example, Automated Surface Observing Systems (ASOS), Automated Weather Observing System (AWOS), or international equivalents. If such a report is not available, weather information based on that pilot's own observations should be used.

9.2.2 *Visibility*—Measure the prevailing visibility determined in statute miles or fractions thereof from the RPIC's usual point of observation. Describe how it was measured and the values. Manually derived visibility shall be evaluated as frequently as practicable. If the prevailing visibility rapidly increases and decreases by ½ statute mile or more, during the time of the observation, and the prevailing visibility is less than three statute miles, the visibility is considered to be variable. The minimum and maximum visibility values observed shall be reported in the remarks section.

9.2.3 *Winds*—Record the direction and speed of the winds at takeoff, winds aloft during cruise from an acceptable weather source as specified in 9.2.1, and at landing. Describe how it was measured and the values (that is, from true or magnetic north and knots or miles per hour). Units shall be consistently used and clearly marked.

9.2.4 *Day/Night*—Record the time of day and calculate sunrise, sunset, and civil/nautical twilight using an almanac such as this one provided by the FAA.[4]

9.2.5 *Sky Cover/Clouds*—Record the cloud base and total amount of coverage in meteorological aerodrome reports (METAR) language ("clear," "scattered," "broken," or "overcast").

[4] See https://avcams.faa.gov/sunrise_sunset.php.

9.2.6 *Temperature*—Record the temperature. Describe how it was measured and the values (Celsius).

9.2.7 *Humidity*—Record the relative humidity level. Describe how it was measured and the values. In the absence of a calibrated hygrometer or reliable weather station data, calculate the dewpoint (°C) using the Magnus formula or equivalent.

$$T_d = \frac{b \cdot \gamma(\mathrm{T, RH})}{a - \gamma(\mathrm{T, RH})} \tag{1}$$

$$\gamma(\mathrm{T, RH}) = \frac{a \cdot T}{b + T} + \ln(\mathrm{RH}) \tag{2}$$

where:

a = 17.27,
b = 237.7 °C, and
Td = dew point.

9.2.8 *Density Altitude*—Record the density altitude at takeoff and at landing in above mean sea level. Describe how it was measured and the values (mmHg). Units shall be consistently used and clearly marked.

9.3 *System Performance Data Content (in accordance with Demonstration):*

9.3.1 *UA Speed*—Record the maximum and minimum speeds in terms of ground speed or airspeed, or both, as appropriate to UA equipage. Units shall be consistently used and clearly marked.

9.3.2 *Maximum UA Range*—Record the direction and distance of the UA from the remote pilot system (RPS) and RPIC. Describe how it was measured and the values (that is, from true or magnetic north and miles). Units shall be consistently used and clearly marked. The following range values shall be recorded.

9.3.2.1 Control and non-payload communications (CNPC) link range.

9.3.3 Radio communication frequency radiation/saturation when required to reflect representative operations and configuration. If so, the following subsections apply.

9.3.3.1 Radio frequency (RF) performance measures for the UA and CS, such as RSSI, shall be recorded during all demonstrations.

9.3.3.2 The RF environment for the point of launch should be characterized for each operating area at least once per site.

9.3.3.3 For UA and CSs intended for operation in environments with increased exposure to high-intensity radiated fields (HIRF), such as in close proximity to power lines, radio broadcast towers, and cellular infrastructure, a more thorough characterization of radiated susceptibility should be performed.

9.4 *Demonstration Card Review:*

9.4.1 Review demonstration cards against demonstration objectives.

9.4.2 Adjust demonstration cards as required to meet stated demonstration objectives and introduce new cards as necessary.

9.4.3 Review environmental data against demonstration objectives and proposed operating limits.

10. Demonstration Program Final Reporting

10.1 After completion of the demonstrations described in the documentation developed in accordance with this practice, one or more final reports shall be written that capture the actual demonstration execution, deviations from the documentation, data collected, and data reduction. The final report may include conclusions or may defer conclusions to a compliance report.

10.1.1 Results can be communicated in various forms, but all data, results, and outcomes shall eventually be consolidated into a final, formal, technical report (or reports) for review by the FAA. The final report is a detailed report that presents analyses, evaluation, and results of the demonstration program.

10.1.2 The final report shall document the demonstration techniques, procedures, and data analysis methods. It needs to be concise and readable, and not contain insignificant details.

10.1.3 The final report shall be organized around the documentation objectives. Each objective shall have a clear finding associated with it. Describe the following: demonstration item; the methods and conditions; the data analyses that helped reach the results; evaluations; and conclusions.

10.1.4 Provide an accurate, unbiased, and balanced assessment of features of the system under demonstration. Present an analysis and evaluation, not just demonstration results, and use data to substantiate all conclusions.

10.2 The final reporting shall consist of one or more reports that shall include the following elements.

10.2.1 Demonstration reports summarizing UA performance and environmental data to adequately characterize the performance envelope. See 1.4 with respect to units for presenting data in demonstration reports.

10.2.2 Overall demonstration results.

10.2.3 General objectives.

10.2.4 *Specific Objectives:*

10.2.4.1 D&R demonstration.

10.2.4.2 Likely failure demonstrations.

10.2.5 Data products and data reduction processing methodology in the form of demonstration data cards, data collections forms (see Appendix X1), summaries of demonstration data, and other relevant information.

10.2.6 Documentation relating to changes resulting from demonstration program regarding the system, handbooks, and manuals.

10.2.7 References to any other documentation, which may include:

10.2.7.1 UFM in accordance with Specification F2908,

10.2.7.2 Maintenance Manual, and

10.2.7.3 Any external data collection forms or media.

11. Keywords

11.1 D&R; demonstration programs; durability and reliability; unmanned aircraft systems; UAS

ANNEXES

(Mandatory Information)

A1. D&R DEMONSTRATION

A1.1 This annex represents the MOC in effect at the time of the drafting of this practice, and it may not reflect changes after publication. Table A1.1 is meant to be used with 8.10.

TABLE A1.1 D&R Demonstration

FAA 21.17(B) Means of Compliance Language	Minimum D&R Demonstrations	Demonstration Case Designator
"Fly a distribution of different operationally representative mission profiles and routes, including highest complexity, as well as flight range and endurance, including maximum allowable."	Accomplish the below.	
a) Weight, including the minimum and maximum proposed.	Include at least three successful flights at 105 % of maximum takeoff weight.	DC1
b) Centers of gravity, including the most adverse laterally and longitudinally, at the most adverse weights.	Include at least three flights with most adverse allowable centers of gravity extremes.	DC2
c) Density altitude for the proposed flight envelope, including the minimum and maximum.	Include at least three flights at minimum and maximum requested air density.	DC3
d) Temperature for the proposed flight envelope, including the minimum and maximum.	Demonstrate at least three flights at maximum and minimum requested temperature range.	DC4
e) Airspeeds that are possible at each different phase of flight.	Rotary-wing and vertical takeoff and landing (VTOL): demonstrate at least three flights at maximum requested airspeed during horizontal phase of flight.	DC5
	Fixed-wing: demonstrate at least three flights with at least 1 min at each of maximum and minimum requested airspeed.	
f) Maximum wind limits and adverse wind directions, including gust conditions at critical phases and modes of flight.	Ensure that demonstration includes wind and gusting conditions of at least 100 % of specified capability at least once.	DC6
g) All weather conditions for which approval is sought.	Demonstrate at least three flights in any weather condition requested as within safe operating envelope.	DC7
h) Time of flight at day and night, if day and night operations are requested.	Record the time of day and available sunlight during each flight. Ensure that if night operations are requested that flight demonstrations include at least three night flights.	DC8
i) Batteries at the worst-case state of charge and depth of discharge or state of health allowable in accordance with procedures, at maximum and minimum outside air temperatures.	Demonstrate at least one battery fail-safe demonstration at both minimum and maximum of requested temperature range.	DC9
j) Aircraft to pilot ratio, including the maximum ratio.	Demonstrate one example of automated flight with requested pilot ratio, all aircraft flying simultaneously. For example, if the requested ratio is 10:1, ten aircraft must be flying a complete mission (takeoff to landing) simultaneously with a single PIC.	DC10
k) If distance from a C2 radio transmitter/receiver is a critical factor, then demonstrate the maximum allowable range from the transmitter/receiver in the most likely worst-case conditions.	Demonstrate at least three flights that reach maximum requested C2 range for at least 1 min without loss of C2 link in an operationally representative environment.	DC11
l) Controllability and safe mission completion must be demonstrated in the following specific demonstration points:	The emphasis here is on combinations of factors.	DC12
1. Minimum weight, most adverse CG, and maximum wind, including max gust and crosswind conditions.	During the course of baseline configuration testing to accumulate required hours, configure one of the three aircraft at minimum specified weight and most adverse CG and at least one of the others at maximum specified weight and adverse CG. Record a) wind, b) gusts, c) temperature, d) density altitude for all flights and report maximums for both configurations.	
2. Maximum weight, most adverse CG, high temperature and density altitude, and maximum mission range/duration.	If representative operations call for more extreme conditions than were encountered in baseline demonstrations, conduct at least one flight in both the minimum and maximum requested weight configuration under the conditions specified in the performance.	
3. Maximum weight, most adverse CG, high temperature and density altitude, and maximum energy expenditure (extended hover or climb, up to maximums expected in service).		
4. High temperature, maximum duration extended ground run before mission.		

A2. LIKELY FAILURE DEMONSTRATIONS

A2.1 This annex represents the MOC in effect at the time of the drafting of this practice, and it may not reflect changes after publication.

TABLE A2.1 Likely Failure Demonstrations

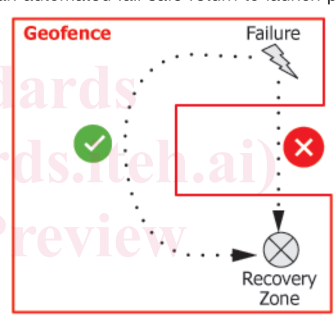
FAA 21.17(B) Means of Compliance Language	Minimum D&R Demonstrations	Demonstration Case Designator
"Evaluate the UAS during the following induced failures, with no loss of control or containment."	Accomplish the below demonstrations at least once with no failures.	
a) Demonstrate the loss of at least one propulsive unit (for example, motor), or the loss of thrust of multiple propulsive units if combined loss is likely. Conduct demonstration at critical mode(s) and phase(s) of flight, maximum weight, and worst-case CG.	If dedicated fail-safe procedures for power loss handling are requested, they must be demonstrated with a system configured to maximum weight and worst-case CG; remotely disable at least one motor while in a critical phase of flight in an automated mission profile. If the aircraft can fly without loss of control with one motor disabled, demonstrate return to launch or return to designated alternate recovery zone under those conditions. If aircraft is unable to fly with one motor disabled, demonstrate automatic parachute deployment or equivalent if equipped, and safe descent.	DC13
b) Demonstrate degradation of the command and control link (link availability is low, quality of service is poor, signal to noise is low, connection is intermittent, latency is high, etc.). Conduct demonstration at critical modes and phases of flight.	Record C2 link performance during demonstration. Demonstrate that at any time signal quality fell below a defined threshold for each metric, and the system responded as specified.	DC14
c) Demonstrate complete loss and non-recovery of the command and control link. Induce link loss at critical modes and phases of flight.	Fully disable the C2 link from the ground at least once for each of these flight phases: takeoff, landing, and transition to and from forward flight. Demonstrate that the aircraft then automatically triggers a fail-safe condition and performs its fail-safe action (such as return to launch after a given delay to attempt to re-establish C2 link).	DC15
d) Demonstrate global positioning system (GPS) degradation at critical modes and phases of flight.	Record global navigation satellite system (GNSS) performance during demonstration. Demonstrate that at any time GNSS quality fell below a defined threshold, the system responded as specified.	DC16
e) Demonstrate complete loss and non-recovery of GPS, with loss occurring at critical modes and phases of flight.	Remotely disable the GNSS link from the ground at least once for each of these flight phases: takeoff, landing, and transition to and from forward flight and geofence proximity. Demonstrate that the aircraft then automatically triggers a fail-safe condition and performs its fail-safe action.	DC17
f) Demonstrate the loss of any critical flight control mechanisms with likely single points of failure. For example, UA with single string servos must demonstrate hard-over failures.	This is primarily relevant to aircraft with aerodynamic control surfaces. Demonstrate a full-deflection lock of one of each kind of control surface at a time (ailerons, elevator, rudder, etc.) showing that the system either can continue in controlled flight or initiates a critical failure descent mode, such as a parachute deployment.	DC18
g) Demonstrate loss of the CS power, operator display, or operator CS control input interface, or combinations thereof.	Power down entire CS during automated mission profile. Demonstrate that the aircraft then automatically triggers a fail-safe condition and performs its fail-safe action.	DC19
h) Demonstrate any other failures you have identified as likely for your UAS.	In accordance with above, construct a demonstration that artificially creates a failure condition in a relevant mission phase and demonstrates that the remedial or fail-safe action is performed as described in the application.	DC20
If multiple aircraft are controlled by one pilot, demonstrate management of a most likely worst-case number of concurrent failures involving multiple aircraft.	If a permitted aircraft:pilot ratio of more than one is specified, conduct an automated flight operation with number of aircraft specified airborne at the same time. Trigger failure modes in at least three aircraft simultaneously, with at least one of those modes requiring PIC action (such as sustained GNSS loss). Demonstrate that the system correctly informs the operator of the failures and identifies which aircraft requires manual intervention.	DC21

A3. SPECIFIC DEMONSTRATIONS

A3.1 This annex represents the MOC in effect at the time of the drafting of this practice, and it may not reflect changes after publication.

TABLE A3.1 Specific Demonstrations

FAA 21.17(B) Means of Compliance Language	Minimum D&R Demonstrations	Demonstration Case Designator
Demonstrate UAS functionality and that no unsafe condition is induced.		
a) Demonstrate the vehicle capability to regain command and control link after the link has been completely lost.	Perform demonstration (c) in Table A2.1 in flight. Then re-enable the C2 link within the system time-out period and demonstrate resumption of control.	DC22
b) If the UFM allows mission continuation after propulsion system degradation, demonstrate safe climb, flight, and landing after the maximum allowable propulsion system degradation at maximum weight and worst-case CG.	Perform demonstration (a) in Table A2.1, but rather than executing a fail-safe procedure, continue an automated mission profile that includes a climb, flight, and landing.	DC23
c) If geofencing is used to maintain safe operations, demonstrate that the logic is capable of containing the UA within the designated area, even in adverse operating conditions, such as maximum winds or after likely UAS failures have occurred.	1) Construct an automated mission that either breaches a static geofence boundary or encounters a dynamic geofence during flight. Demonstrate that the UA detects the potential breach prior to its occurrence and initiates the applicant's specified geofence breach behavior prior to crossing the geofence line. 2) Repeat with maximum available winds, attempting to breach a downwind geofence barrier. 3) If representative operations allow for missions in which a straight line from any waypoint to a recovery zone that intersects a geofence boundary, construct a geofence barrier as shown in the diagram below such that the UA cannot travel in a straight line from a failure point to the recovery zone without breaching a geofence. Demonstrate that the UA repsects the geofence boundary in an automated fail-safe return-to-launch path.	DC24



FAA 21.17(B) Means of Compliance Language	Minimum D&R Demonstrations	Demonstration Case Designator
d) Demonstrate that the electrical system operates safely even at maximum loads, and that bus loads and capacity are adequate to power all aircraft systems and payloads.	Demonstrate a full power load automated mission with a payload powered by the aircraft's electrical system that is drawing maximum specified current in the UFM for the duration of the mission.	DC25
e) Demonstrate the ability to recall a UA.	During an automated mission, PIC initiates a recall command. Mission must execute recall procedures without violating operational limitations or breaching geofence barriers (if any).	DC26
f) Demonstrate the ability to dynamically reroute a UA in real time.	During an automated mission, PIC commands a changed mission, uploading new waypoints. Aircraft must halt current mission and begin new mission without breaching geofence barriers (if any).	DC27
g) Demonstrate the ability to abort a takeoff.	PIC initiates an automated takeoff. For rotary-wing aircraft, before commanded height is reached, PIC must halt or pause takeoff and the aircraft must stop or land without loss of control. For fixed-wing aircraft, initiate an automated takeoff command. Before takeoff is achieved, PIC cancels that command. Aircraft must come to a stop without loss of control.	DC28
h) Demonstrate the ability to abort a landing and go-around or re-attempt.	While aircraft is hovering, PIC initiates an automated landing command. During the descent, PIC halts or pauses the landing. For rotary-wing aircraft, the aircraft must hover at the altitude reached when the abort command was issued. For fixed-wing UA, once the PIC cancels the landing command, the aircraft must demonstrate a return to a positive climb gradient and successful landing pattern re-entry.	DC29