Designation: F 2501 – 06

Standard Practices for Unmanned Aircraft System Airworthiness[1]

This standard is issued under the fixed designation F 2501; 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 These practices identify existing regulations, standards, specifications, and handbooks to guide the design, manufacture, test, repair, and maintenance of unmanned aircraft systems and their components.

1.2 *Applicability*—These practices apply to unmanned, powered, fixed wing aircraft and rotorcraft systems seeking government aviation authority approval in the form of airworthiness certificates, flight permits, or other like documentation. It is intended to be used as a reference by unmanned aircraft system designers and manufacturers, as well as by procurement authorities, to help ensure the airworthiness of these systems.

1.3 These practices provide a starting point for developing a standards-based airworthiness certification package for consideration by regulatory authorities. It lists those top-level standards applicable to the major subsystems and components of an unmanned aircraft system. It assumes that Original Equipment Manufacturer (OEM)-provided subsystems and components, purchased and installed as a unit (for example, Global Positioning Systems), are themselves built to applicable standards that are not necessarily listed in these practices. These practices include standards for technologies that are currently in use in unmanned aircraft, as well as those that are not yet, but could be used in the future (for example, radioisotope thermoelectric generators).

1.4 Suggested changes, corrections, or updates should be forwarded to Committee F38.

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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

B 117 Practice for Operating Salt Spray (Fog) Apparatus

D 910 Specification for Aviation Gasolines

D 1655 Specification for Aviation Turbine Fuels

F 2279 Practice for Quality Assurance in the Manufacture of Light Sport Airplanes

F 2316 Specification for Airframe Emergency Parachutes for Light Sport Aircraft

F 2339 Practice for Design and Manufacture of Reciprocating Spark Ignition Engines for Light Sport Aircraft

F 2395 Terminology for Unmanned Air Vehicle Systems

F 2411 Specification for Design and Performance of an Airborne Sense-and-Avoid System

2.2 *AIAA Document:*[3]

AIAA R-103-2004 Terminology for Unmanned Aerial Vehicles and Remotely Operated Aircraft

3. Referenced Practices

3.1 The regulations, standards, specifications, and handbooks cited as recommended practices herein are referenced for use in the following precedence: U.S. Federal Aviation Administration (FAA) regulations and advisory circulars; U.S. Department of Defense (DoD) standards, specifications and handbooks; documents produced by other government agencies; and non government standards (NGS) produced by standards development organizations (SDOs) and similar bodies. Suffixes indicating editions of referenced standards are omitted to reduce the frequency of updates to these practices. Non-current standards are so indicated at the end of their titles.

3.2 References are made to standards written specifically for other than unmanned aircraft (for example, light sport aircraft) and for human considerations (for example, personal parachutes) where they are judged to have some degree of parallel applicability to unmanned aircraft design and use.

4. Terminology

4.1 Refer to Terminology F 2395 and AIAA R-103-2004 for definitions of terms used in these practices.

4.2 *Abbreviations:*

4.2.1 The following abbreviations are used in the titles of the referenced documents.

4.2.2 *AC*—Advisory Circular (FAA)

4.2.3 *AFGS*—Air Force Guides Specifications (DoD)

[1] These practices are under the jurisdiction of ASTM Committee F38 on Unmanned Aircraft Systems and are 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 American Institute of Aeronautics and Astronautics (AIAA), 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344.

4.2.4 *AIAA*—American Institute of Aeronautics and Astronautics

4.2.5 *ANSI*—American National Standards Institute

4.2.6 *ARINC*—Aeronautical Radio, Incorporated

4.2.7 *ASTM*—American Society for Testing and Materials (ASTM International)

4.2.8 *BS*—British Standard

4.2.9 *CFR*—Code of Federal Regulations

4.2.10 *EUROCAE*—European Organisation for Civil Aviation Equipment

4.2.11 *IEC*—International Electrotechnical Commission

4.2.12 *IEEE*—Institute of Electrical and Electronics Engineers

4.2.13 *ISO*—International Standards Organization

4.2.14 *JEDEC*—Joint Electron Device Engineering Council

4.2.15 *JIS*—Japanese Industrial Standard

4.2.16 *JSSG*—Joint Services Specification Guides (DoD)

4.2.17 *MIL HDBK*—Military Handbook (DoD)

4.2.18 *MIL STD*—Military Standard (DoD)

4.2.19 *NASA*—National Aeronautics and Space Administration (U.S.)

4.2.20 *RTCA*—Radio Technical Commission for Aeronautics

4.2.21 *SAE*—Society of Automotive Engineers

5. Summary of Practice

5.1 These practices provide references to currently available published standards and practices having wide acceptance in the aviation community and specific applicability to the unmanned aviation community. These standards and practices address material selection (design), structural fabrication and repair (manufacturing), and inspection and quality control (testing) of aviation-quality components and systems. It does not address operating procedures, operator qualifications, or other non-material determinants of system quality and safety. It is recognized that not all of these standards and practices will be equally applicable to all models of unmanned aircraft.

5.2 *Organization of Recommended Practices* (Section 7):

6. Significance and Use

6.1 Designing, manufacturing, testing, and maintaining an unmanned aircraft system to comply with industry standards and recommended practices supports development of a certification package that helps ensure its reliability and can lead to its airworthiness certification. Government aviation authorities' airworthiness certification processes exist to provide some level of assurance that critical systems will operate reliably and pose minimal risk to persons and property. The use of proven standards and practices in the design, manufacture, and test of these systems, especially for the mission critical components, contributes to this goal, as well as streamlining the certification process and simplifying the system test requirements. While developing to a set of standards and practices will not guarantee certification, the ability to show compliance with established standards provides the basis for a well-documented certification approval package.

6.2 Compliance with established standards and practices also provides assurance that a given component will function as intended in the specified environment and conditions. The standards cited in these practices have been developed by recognized standards-developing agencies; some are accepted by government aviation authorities as an acceptable means of compliance with airworthiness requirements. By their inclusion in these practices, they are considered to be consensus-based for unmanned aircraft-related purposes.

7. Recommended Industry Practices

7.1 *Airframe*—Aircraft materials and structures largely determine the performance limitations (g-loads, flutter, and so forth), safety, and affordability of the overall system. The type and quality of the materials used in these structures, as well as the methods by which they are molded, joined, attached, and repaired, directly impact these three areas. They also impact the equipping and layout of the manufacturer's production floor and the hiring (skill level demands) of production floor employees.

14 Code of Federal Regulations (CFR) Part 21—Certification Procedures for Products and Parts

14 Code of Federal Regulations (CFR) Part 23—Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes

14 Code of Federal Regulations (CFR) Part 25—Airworthiness Standards: Transport Category Airplanes

14 Code of Federal Regulations (CFR) Part 27—Airworthiness Standards: Normal Category Rotorcraft

14 Code of Federal Regulations (CFR) Part 29—Airworthiness Standards: Transport Category Rotorcraft

14 Code of Federal Regulations (CFR) Part 39—Airworthiness Directives

FAA Order 8130.2E—Airworthiness Certification of Aircraft and Related Products–The FAA and Industry Guide to Aviation Product Certification

FAA-H-8083-1—Aircraft Weight and Balance Handbook—An FAA guide to help developers successfully complete the civil certification process.

FAA-AC-23-17b—Guide for Certification of Part 23 Aircraft

FAA AC 43.13-1B—Acceptable Methods, Techniques, and Practices—Aircraft Inspection and Repair—A description of methods, techniques, and practices for inspecting and repairing wood, fabric, fiberglass, plastic, and metal airframe components, and conducting nondestructive and corrosion inspection. It also addresses aircraft hardware, engines and propellers, landing gear, hydraulics, electrical systems and wiring, batteries, avionics, and pitot static systems.

MIL-HDBK-514—Operational Safety, Suitability, and Effectiveness for the Aeronautical Enterprise

MIL-HDBK-516—Airworthiness Certification Criteria—The DoD-wide guidance (not requirements) for all aspects of airworthiness certification, Cross references its paragraphs with JSSG standards and FAA 14 CFR Parts, and includes criteria for shipborne aircraft.

JSSG-2001B—Air Vehicle

JSSG-2009—Air Vehicle Subsystems

ASTM Practice F 2279—Practice for Quality Assurance in the Manufacture of Light Sport Airplanes

7.1.1 *Materials*:

7.1.1.1 *Metals*:

FAA AC 25.613-1X—Material Strength Properties and Material Design Values

MIL-HDK-5—Metallic Materials and Elements for Aerospace Vehicle Structures—A description of material properties (strength, fracture toughness, fatigue strength, creep strength, crack propagation rate, resistance to corrosion, and so forth) for metallic materials and fasteners commonly used in airframes to determine design allowables.

7.1.1.2 *Non-Metals*:

(1) MIL-HDBK-17—Composite Materials Handbook—A description of material properties of non-metallic materials commonly used in airframes such as fiber glass and carbon composites.

(2) SAE-AMS-PRF 46194—Foam, Rigid, Structural, Closed Cell

(3) SAE-AMS-STD 401—Sandwich Constructions and Core Materials; General Test Methods

7.1.2 *Structures*:

14 Code of Federal Regulations (CFR) Part 43—Maintenance, Preventative Maintenance, Rebuilding, and Alteration

FAA AC 20-107A—Composite Aircraft Structures

FAA AC 25.571-1C—Damage-Tolerance and Fatigue Evaluation of Structure

FAA AC 43.13-2A—Acceptable Methods, Techniques, and Practices—Aircraft Alterations

MIL-HDBK-1530—General Guidelines for Aircraft Structural Integrity Program

JSSG-2006—Aircraft Structures

National Aeronautics and Space Administration Technical Memorandum (NASA/TM)-1998-208456—Low-Cost Quality Control and Nondestructive Evaluation Technologies for General Aviation Structures

RTCA DO-213—Minimum Operational Performance Standards for Nose-Mounted Radomes

SAE-AE-27—Design of Durable, Repairable, and Maintainable Aircraft Composites

SAE-ARP-1611—Quality Inspection Procedure, Composites, Tracer Fluoroscopy and Radiography

SAE-ARP-5089—Composite Repair NDT/NDI Handbook

7.1.3 *Flight Controls*:

JSSG-2008—Vehicle Control and Management System (VCMS)

SAE-AIR-4094—Aircraft Flight Control Systems Descriptions

SAE-ARP-4386—Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies

7.1.3.1 *Actuators*:

MIL-STD-5522—Test Requirements and Methods for Aircraft Hydraulic and Emergency Pneumatic Systems

SAE-ARP-988—Electrohydraulic Mechanical Feedback Servoactuators

SAE-AIR-4253—Description of Actuation Systems for Aircraft with Fly-By-Wire Flight Control Systems

SAE-ARP-4895—Aerospace—Flight Control Actuator Displacement—Method for Collection of Duty Cycle Data

(1) Electrical:

SAE-ARP-4255—Electrical Actuation Systems for Aerospace and Other Applications

(2) Gas:

SAE-ARP-777—Gas Actuators (Linear and Vane Rotary Type)

(3) Hydraulic:

MIL-H-87227—Hydraulic Power Systems

SAE-ARP-1281—Actuators: Aircraft Flight Controls, Power Operated, Hydraulic, General Specification for

SAE-AIR-1899—Aerospace Military Aircraft Hydraulic System Characteristics

SAE-AIR-4543—Aerospace Hydraulics and Actuation Lessons Learned

SAE-AIR-5005—Aerospace—Commercial Aircraft Hydraulic Systems

SAE-AS-5440—Hydraulic Systems, Aircraft, Design and Installation Requirements for

(4) Mechanical:
SAE-ARP-4058—Actuators: Mechanical, Geared Rotary, General Specification for
(5) Pneumatic:
MIL-P-87210—Pneumatic Power Systems, High Pressure
7.1.3.2 *Control Linkages*:
MIL-B-87146—Bearings, Pulleys, and Cables, General Specification for
7.1.3.3 *Autopilots—(see also* 7.3.3*)*:
MIL-STD-1797A—Flying Qualities of Piloted Aircraft
SAE-AS-402—Automatic Pilots
SAE-ARP-419—Automatic Pilot Installations
SAE-AS-440—Automatic Pilots (Turbine Powered Subsonic Aircraft)
AE-ARP-4102/5—Primary Flight Controls by Electrical Signaling Section 1
SAE-AIR-4982—Aerospace Fly-By-Light Actuation Systems
7.1.4 *Landing Gear*:
AFGS-87139A—Landing Gear Systems
SAE-ARP-693—Landing and Taxiing Lights—Design Criteria for Installation
SAE-ARP-1311—Aircraft Landing Gear
SAE-AIR-1489—Aerospace Landing Gear Systems Terminology
SAE-AIR-1494—Verification of Landing Gear Design Strength
SAE-ARP-1598—Landing Gear System Development Plan
SAE-AIR-4243—Landing Area/Landing Gear Compatibility—A Brief History of SAE/Corps of Engineers Cooperation
SAE-AIR-4566—Crashworthy Landing Gear Design
7.1.4.1 *Wheels/Brakes/Anti-Skid Control*:
SAE-ARP-813—Maintainability Recommendations for Aircraft Wheel and Brake Design
SAE-ARP-1070—Design and Testing of Antiskid Brake Control Systems for Total Aircraft Compatibility
SAE-ARP-1493—Wheel and Brake Design and Test Requirements for Military Aircraft
SAE-ARP-1595—Aircraft Nosewheel Steering Systems
SAE-ARP-1907A—Automatic Braking Systems Requirements
SAE-AIR-5372—Information on Brake-By-Wire Brake Control Systems
SAE-ARP-5381—Minimum Performance Recommendations for Part 23, 27, and 29 Aircraft Wheels, Brakes, and Wheel and Brake Assemblies
SAE-AIR-5388—Unique Wheel and Brake Designs
7.1.4.2 *Gears/Struts/Couplings*:
SAE-AS–6053—Tests, Impact, Shock Absorber Landing Gear, Aircraft
7.1.4.3 *Tires*:
FAA TSO-C62d—Technical Standard Order: Aircraft Tires
MIL-T-504—Military Specification (USAF) Tires, Pneumatic, Aircraft
JIS W2502—Japanese Industrial Standard for Aircraft Tires
SAE-AS1188—Aircraft Tire Inflation—Deflation Equipment
SAE-ARP-5265—Minimum Operational and Maintenance Responsibilities for Aircraft Tire Usage
SAE-AIR-5487—Aircraft Tire History
7.1.5 *Launch Devices*.
7.1.6 *Recovery Devices*:
MIL-DTL-7620—Parachutes and Components, Cargo, Extraction and Deceleration, General Specification for
ASTM Specification F 2316—Specification for Airframe Emergency Parachutes for Light Sport Aircraft
SAE-AS-8015—Minimum Performance Standard for Parachute Assemblies and Components, Personnel
7.1.7 *Environmental*:
SAE-AS-5778—Covers, Aircraft Components, General Requirements for
7.1.7.1 *External (Ambient) Environment*:
MIL-STD-202—Test Method Standard, Electronic and Electrical Component Parts
MIL-STD-810—Environmental Engineering Considerations and Laboratory Tests
RTCA DO-160—Environmental Conditions and Test procedures for Airborne Equipment
(1) Altitude (Temperature/Pressure/Humidity):
MIL-HDBK-310—Global Climatic Data for Developing Military Products
ISO 5878:1982—Reference Atmospheres for Aerospace Use
(2) Rain/Ice/Wind:
SAE AIR1168/4—Ice, Rain, Fog, and Frost Protection
(3) Dust/Salt Fog:
ASTM Practice B 117—Practice for Operating Salt Spray (Fog) Apparatus
(4) Fungus:
MIL-STD-810—Environmental Engineering Considerations and Laboratory Tests
(5) Lightning/EMI/HIRF:
MIL-STD-461—Electromagnetic Emission and Susceptibility Requirements for the Control of EMI.
MIL-STD-462—Measurement of Electromagnetic Interference (EMI) Characteristics
SAE-ARP-5412—Aircraft Lightning Environment and Related Test Waveforms
SAE-ARP-5413—Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning
SAE-ARP-5416—Aircraft Lightning Test Methods
SAE-ARP-5577—Aircraft Lightning Direct Effects Certification
SAE-ARP-5583—Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment
SAE-ARP-5889—Alternative (Ecological) Method for Measuring Electronic Product Immunity to External Electromagnetic Fields
(6) Solar Weather:
JEDEC JESD-89—Measurement and Reporting of Alpha Particles and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices
7.1.7.2 *Internal (Onboard) Environment*:
AFGS-87145—Environmental Control, Airborne
RTCA DO-160—Environmental Conditions and Test Procedures for Airborne Equipment

SAE-ARP-147—Environmental Control Systems Terminology

SAE-ARP-217—Testing of Airplane Installed Environmental Control Systems (ECS)

SAE-ARP-780B—Environmental Systems Schematic Symbols

(1) Temperature:

MIL-B-23071—Blowers, Miniature, for Cooling Electronic Equipment

SAE-AIR-64—Electrical and Electronic Equipment Cooling in Commercial Transports

SAE-ARP-85—Air Conditioning Systems for Subsonic Airplanes

SAE-ARP-86—Heater, Airplane, Engine Exhaust Gas to Air Heat Exchanger Type. (Noncurrent)

SAE-AIR-89—Aircraft Compartment Automatic Temperature Control Systems

SAE-AIR-860—Aircraft Electrical Heating Systems

SAE-AIR-1277—Cooling of Military Avionic Equipment

SAE-AS-8040—Heater, Aircraft, Internal Combustion Heat Exchanger Type

(2) Pressure:

SAE-AIR-1168/7—Aerospace Pressurization System Design

SAE-ARP-1270—Aircraft Cabin Pressurization Control Criteria

(3) Humidity:

SAE-ARP-987—The Control of Excess Humidity in Avionics Cooling

SAE-AIR-1609—Aircraft Humidification

(4) Shock/Vibration/Acceleration:

MIL-STD-167-1—Mechanical Vibration of Shipboard Equipment (Type 1—Environmental and Type 1 i—Internally Excited)

MIL-STD-202—Test Method Standard, Electronic and Electrical Component Parts

MIL-STD-810—Environmental Engineering Considerations and Laboratory Tests

MIL-S-901—Shock Tests, High (High Impact) Shipboard Machinery, Equipment and Systems, Requirements for Navy

(5) Acoustic:

MIL-STD-1474—Noise Limits

SAE-AIR-1826—Acoustical Considerations for Aircraft Environmental Control System Design

(6) Electromagnetic Interference/Compatibility (EMI/EMC):

MIL-HDBK-237—Electromagnetic Compatibility/Interference Program Requirements

MIL-STD-461—Electromagnetic Emission and Susceptibility Requirements for the Control of EMI

MIL-STD-462—Measurement of Electromagnetic Interference (EMI) Characteristics

MIL-STD-464—Electromagnetic Environmental Effects, Requirements for Systems

SAE-ARP-1870—Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety

SAE-ARP-1972—Recommended Measurement Practices and Procedures for EMC Testing

SAE-AIR-5060—Electronic Engine Control Design Guide for Electromagnetic Environmental Effects

7.1.8 *Other (Airframe)*.

7.2 *Power and Propulsion*—Some unmanned aircraft have employed non-aviation certified engines to reduce their acquisition cost. These engines were designed for operation in less demanding environments than aviation and to use lower quality fuels. This practice, however, has led to many accidents and been a prime contributor to the poor reliability record of certain unmanned aircraft. Three out of every eight U.S. military unmanned aircraft accidents are attributed to power plant failures.[4] Therefore, the use of power plants and fuels manufactured to relevant aviation standards is key to improving the reliability of unmanned aircraft. Good design practice also dictates that the equipment and systems installed in aircraft neither present a single-point failure, nor are able to induce cascade type failures. This philosophy is embodied in Section 1309 of both 14 CFR 23 and 14 CFR 25.

14 Code of Federal Regulations (CFR) Part 33—Airworthiness Standards, Aircraft Engines

14 Code of Federal Regulations (CFR) Part 36—Noise Standards, Aircraft Type and Airworthiness Certification

FAA AC 23.1309—Equipment, Systems and Installations in Part 23 Airplanes

FAA AC/AMJ 25.1309—System Design and Analysis

FAA AC 43.13-1B—Acceptable Methods, Techniques, and Practices–Aircraft Inspection and Repair—A description of methods, techniques, and practices for inspecting and repairing wood, fabric, fiberglass, plastic, and metal airframe components, and conducting nondestructive and corrosion inspection. It also addresses aircraft hardware, engines and propellers, landing gear, hydraulics, electrical systems and wiring, batteries, avionics, and pitot static systems.

MIL-HDBK-516—Airworthiness Certification Criteria—The DoD-wide guidance (not requirements) for all aspects of airworthiness certification. Cross references its paragraphs with JSSG standards and FAA 14 CFR Parts; includes criteria for shipborne aircraft.

Society of Automotive Engineers (SAE), Committee E25, General Standards for Aeronautical Propulsion Systems—This series of standards establishes constant quality utility part standards for aerospace propulsion engines and propellers including bolts, screws, nuts, washers, studs, rivets, pins, fluid fittings, gaskets, covers, O-rings, brackets, clamps, plugs, as well as design specifications for screw threads and fastener assembly requirements.[5]

SAE-AS-177—Operating Instructions for Aircraft Engine (Preparation of)

SAE-AIR-1703—n-Flight Thrust Determination

SAE-AIR-4250—Electronic Engine Control Specifications and Standards

7.2.1 *Reciprocating Engines*:

14 Code of Federal Regulations (CFR) Part 33—Airworthiness Standards, Aircraft Engines

[4] Office of the Secretary of Defense, Unmanned Aerial Vehicle Reliability Study, February 2003.

[5] A current list of these standards can be found at: http://www.sae.org/servlets/product?PROD_TYP=STD&HIER_CD=TEAE25&SLC_SW=YES.

ASTM Practice F 2339—Practice for Design and Manufacture of Reciprocating Spark Ignition Engines for Light Sport Aircraft

SAE-AS-13—Magnetos, Aircraft, Drives For (Non-current)

SAE-AS-1—Altitude Graphs, Aircraft Reciprocating Engine Performance

SAE-AIR-4065—Propeller/Propfan In-flight Thrust Determination

SAE-AS-25109—Engines, Aircraft, Reciprocating, General Specification for

7.2.2 *Turbine Engines*:

14 Code of Federal Regulations (CFR) Part 34—Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes

JSSG-2007A—Engines, Aircraft, Turbine

AFGS-87271—Engines, Unmanned Air Vehicle, Airbreathing, Gas Turbine, Expendable

SAE-ARP-748—Gas Turbine Engine Power Take-Off Pad Requirements

SAE-AIR-1872—Guide to Life Usage Monitoring and Parts Management for Aircraft Gas Turbine Engines

7.2.3 *Electric Motors*:

IEC 60034—Rotating Electrical Machines

IEC 60072—Dimensions and Output Series for Rotating Electrical Machines

7.2.3.1 *Batteries*:

MIL-HDBK-1860—Batteries, Non-Rechargeable, Selection and Use of

MIL-B-8565—Battery, Storage, Aircraft, Medium-Rate, Type 1, Maintenance-Free, 24-Volt, 10-Ampere-Hours

IEC 21/466/CD—Aircraft Batteries. Part 1. General Test Requirements and Performance Levels

IEC 21/509/CD—Aircraft Batteries. Part 2. Design and Construction Requirements

IEC 21/510/CD—Aircraft Batteries. Part 3. External Electrical Connectors

IEC 952-1—Aircraft Batteries

RTCA DO-227—Minimum Operational Performance Standards for Lithium Batteries

RTCA DO-293—Minimum Operational Performance Standards for Nickel-Cadmium and Lead Acid Batteries

SAE-AS-8033—Nickel Cadmium Vented Rechargeable Aircraft Batteries (Non-Sealed, Maintainable Type)

7.2.3.2 *Fuel Cells*:

SAE-J2574—Fuel Cell Vehicle Technology

SAE-J2578—Recommended Practice for General Fuel Cell Vehicle Safety

SAE-AMSS-8802—Sealing Compound, Temperature Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion

7.2.3.3 *Solar Cells (Photovoltaic)*:

IEC 61427—Secondary Cells and Batteries for Solar Photovoltaic Energy Systems—General Requirements and Methods of Test

7.2.3.4 *Radioisotope (Thermoelectric)*:

SAE-AIR-1213—Radioisotope Power Systems

7.2.4 *Propellers*:

14 Code of Federal Regulations (CFR) Part 35—Airworthiness Standards: Propellers

SAE-AS-107—Surface Finish (RMS). (Non-current)

SAE-ARP-355—Terminology of Dual and Coaxial Counter-Rotating Propellers

7.2.5 *Electrical Distribution Systems*:

MIL-E-7016—Electric Load and Power Source Capacity, Aircraft, Analysis of

AFGS-87219A—Electrical Power Systems, Aerospace Vehicles

RTCA DO-167—Airborne Electronics and Electrical Equipment Reliability

SAE-AS-1212—Electric Power, Aircraft, Characteristics and Utilization of

SAE-AIR-1336—Vehicle Electrical Systems

SAE-ARP-4404—Aircraft Electrical Installations

SAE-ARP-5584—Document for Electric Power Management

SAE-AS-81099—Electric Devices, Simple, General Specification for

7.2.5.1 *Generators/Converters*:

MIL-HDBK-705—Generator Sets, Electrical, Measurements and Instrumentation Methods

SAE-AIR-1160—Aircraft Engine and Accessory Drives and Flange Standards

SAE-AS-4361—Minimum Performance Standards for Aerospace Electric Power Converters

SAE-AS-8011—Minimum Performance Standards for A-C Generators and Associated Regulators

7.2.5.2 *Starters*:

SAE-AIR-1174—Index of Starting System Specifications and Standards

SAE-AIR-1602—Starter System Optimization, Start Analysis, Turbine Engine—Electric, Battery Power

SAE-AIR-4161—Introduction to Starting Systems

7.2.5.3 *Wiring*:

MIL-W-5088—Wiring, Aerospace Vehicles

SAE-ARP-1308—Preferred Electrical Connectors for Aerospace Vehicles and Associated Equipment (Non-current)

7.2.6 *Fuel Systems*:

AFGS-87154A—Fuel Systems, General Design Specification for

SAE-AIR-1408—Aerospace Fuel System Specifications and Standards

SAE-AIR-1662—Minimization of Electrostatic Hazards in Aircraft Fuel Systems

7.2.6.1 *Fuels*:

ASTM Specification D 910—Specification for Aviation Gasolines.

ASTM Specification D 1655—Specification for Aviation Turbine Fuels

7.2.6.2 *Pumps/Valves/Meters*:

SAE-AS-407—Fuel Flowmeters

SAE-AS-431—True Mass Fuel Flow Instruments

SAE-AS-445—Fuel and Oil Quantity Instruments (Turbine Powered Subsonic Aircraft). (Non-current)

SAE-AIR-1326—Aircraft Fuel System Vapor-Liquid Ratio Parameter

SAE-AIR-1660—Fuel Level Control Valves/Systems

SAE-AS-8029—Minimum Performance Standard for Fuel and Oil Quantity Indicating System Components

7.2.6.3 *Tanks and Plumbing*:

14 Code of Federal Regulations (CFR) Part 34—Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes

BS 2F 67:1980—Specification for Hose for Aviation Fuel and Engine Lubricating Oil for Aeronautical Purposes

BS EN 1361:2004—Rubber Hoses and Hose Assemblies for Aviation Fuel Handling

SAE-AIR-1664 —Aircraft Flexible Tanks, General Design and Installation Recommendations

SAE-AIR-4069—Sealing Integral Fuel Tanks

SAE-AIR-5128—Electrical Bonding of Aircraft Fuel System Plumbing Systems

SAE-AS-5502—Standard Requirements for Aerospace Sealants

SAE-AMSS-8802—Sealing Compound, Temperature Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion

SAE-AS-18802—Fuel and Oil Lines, Aircraft, Installation of

7.2.7 *Other (Power and Propulsion)*:

MIL-A-87229—Auxiliary Power Systems, Airborne

7.3 *Avionics*—Avionics (aviation electronics) tend to be delivered to the aircraft manufacturer in a preassembled, ready-to-install configuration. Avionics OEMs build their products to their particular industries' standards, which are not covered in tthese practices. The avionics-related standards covered here deal with their physical and electrical integration and their installed performance requirements. Avionics requirements become the driver for unmanned aircraft internal environment requirements in the absence of having humans onboard.

FAA AC 43.13-1B—Acceptable Methods, Techniques, and Practices—Aircraft Inspection and Repair—A description of methods, techniques, and practices for inspecting and repairing wood, fabric, fiberglass, plastic, and metal airframe components, and conducting nondestructive and corrosion inspection. It also addresses aircraft hardware, engines and propellers, landing gear, hydraulics, electrical systems and wiring, batteries, avionics, and pitot static systems.

MIL-STD-202—Test Method Standard, Electronic and Electrical Component Parts

MIL-HDBK-516—Airworthiness Certification Criteria—The DoD-wide guidance (not requirements) for all aspects of airworthiness certification; cross references its paragraphs with JSSG standards and FAA 14 CFR Parts and includes criteria for shipborne aircraft.

MIL-HDBK-87244—Avionics/Electronics Integrity

JSSG-2005-03—Guidance for the Preparation of the Avionic Subsystem Missionized Profile for the Unmanned Air Vehicle

AFGS-87256—Integrated Diagnostics

RTCA DO-167—Airborne Electronics and Electrical Equipment Reliability

RTCA DO-216—Minimum General Specification for Ground-Based Electronic Equipment

RTCA DO-254—Design Assurance Guidance For Airborne Electronic Hardware

SAE-ARP-4754/EUROCAE ED-79—Certification Considerations for Highly Integrated or Complex Aircraft Systems

SAE-ARP-4927—Integration Procedures for the Introduction of New Systems to the Cockpit

SAE-AS-8700—Installation and Test of Electronic Equipment in Aircraft, General Specification for

7.3.1 *Communication and Navigation*:

FAA AC 20-130—Airworthiness Approval of Multi-sensor Navigation Systems for use in the National Airspace System

FAA AC 20-138—Airworthiness Approval of NAVSTAR Global Positioning System (GPS) for use as a VFR and IFR Supplemental Navigation System

FAA AC 25-4—Inertial Navigation Systems (INS)

FAA AC 90-45A—Approval of Area Navigation Systems for use in the U.S. National Airspace System

RTCA DO-88—Altimetry

RTCA DO-155—Minimum Performance Standards—Airborne Low-Range Radar Altimeters

RTCA DO-187—Minimum Operational Performance Standards (MOPS) for Airborne Area Navigation Equipment Using Multi Sensor Inputs. See also FAA TSO-C115b, Airborne Area Navigation Equipment Using Multi Sensor Inputs.

RTCA DO-193—User Requirements for Future Communications, Navigation, and Surveillance Systems, Including Space Technology Applications

RTCA DO-208—Minimum Operational Performance Standards (MOPS) for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS). See also FAA TSO-C129a, Airborne Supplemental Navigation Equipment Using Global Positioning System.

RTCA DO-228—Minimum Operational Performance Standards (MOPS) for Global Navigation Satellite Systems (GNSS) Airborne Antenna Equipment

RTCA DO-229—Minimum Operational Performance Standards (MOPS) for Global Positioning System/Wide Area Augmentation System Airborne Equipment

RTCA DO-253—Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment

RTCA DO-278—Guidelines for Communication, Navigation, Surveillance, and Air Traffic Management (CNS/ATM) Systems Software Integrity Assurance

SAE ARP4102/6—Communications and Navigation Equipment

7.3.2 *Safety and Situational Awareness*:

MIL-STD-882—System Safety Program Requirements

SAE-AS-439—Stall Warning Instrument (Turbine Powered Subsonic Aircraft)

SAE-AS-8014—Minimum Performance Standard, Stall Warning Equipment

SAE-AS-8046—Minimum Performance Standard, Angle of Attack Equipment

7.3.2.1 *Lighting and Placards*:

14 Code of Federal Regulations Part 23.1397—Color Specifications

SAE-ARP-693—Landing and Taxiing Lights—Design Criteria for Installation

SAE-AS-827—Aircraft Anti-Collision Lights. (cancelled)

SAE-ARP-991—Position and Anticollision Lights—Turbine Powered Fixed Wing Aircraft

SAE-AIR-1106—Some Factors Affecting Visibility of Aircraft Navigation and Anticollision Lights

SAE-AS-8017—Minimum Performance Standard for Anticollision Light Systems

SAE-AS-8037—Minimum Performance Standard for Aircraft Position Lights

7.3.2.2 *Sense and Avoidance*:

ASTM Specification F 2411—Specification for Design and Performance of Airborne Sense and Avoid Systems

RTCA DO-161—Minimum Performance Standards—Airborne Ground Proximity Warning Equipment

RTCA DO-184—Traffic Alert and Collision Avoidance System (TCAS) I Functional Guidelines

RTCA DO-185—Minimum Operational Performance Standards (MOPS) for Traffic Alert and Collision Avoidance System II (TCAS II) Airborne Equipment

RTCA DO-197—Minimum Operational Performance Standards (MOPS) for an Active Traffic Alert and Collision Avoidance System I (Active TCAS I)

RTCA DO-263—Application of Airborne Conflict Management: Detection, Prevention, & Resolution

SAE ARP4102/10—Collision Avoidance System

SAE ARP5365—Human Interface Criteria for Cockpit Display of Traffic Information

7.3.2.3 *Transponders*:

14 Code of Federal Regulations (CFR) Part 91.215—ATC Transponder and Altitude Reporting Equipment and Use

FAA TSO C74c—Airborne ATC Transponder Equipment

7.3.2.4 *Weather Avoidance/Mitigation*:

RTCA DO-191—Minimum Operational Performance Standards for Airborne Thunderstorm Detection Equipment

RTCA DO-220—Minimum Operational Performance Standards (MOPS) for Airborne Weather Radar with Forward-Looking Windshear Detection Capability

SAE-AIR-4015—Icing Technology Bibliography

SAE-AIR-4367—Aircraft Ice Detectors and Icing Rate Measuring Instruments

SAE-ARP-4737—Aircraft Deicing/Anti-Icing Methods

SAE-AIR-5396—Characterizations of Aircraft Icing Conditions

SAE-AS-5498—Minimum Operational Performance Specification for Inflight Icing Detection Systems

7.3.3 *Computers*:

MIL-STD-202—Test Method Standard, Electronic and Electrical Component Parts

SAE-AIR-4893—Generic Open Architecture (GOA) Framework Standard

SAE-AIR-5315—Overview and Rationale for GOA Framework Standard

SAE-AS-5506—Avionics Architecture Description Language (AADL)

7.3.3.1 *Hardware*:

MIL-STD-750—Test Method Standard for Semiconductor Devices

MIL-STD-883—Test Method Standard, Microcircuits

SAE-ARP-1612—Polyamide Printed Circuit Boards, Fabrication of

7.3.3.2 *Software*:

ARINC Specification 653—Defines a general-purpose Application/Executive (APEX) software interface between the Operating System of an avionics computer and the application software. The interface requirements between the application software and operating system services are defined in a manner that enables the application software to control the scheduling, communication, and status of internal processing elements.

RTCA DO-178—Software Considerations in Airborne Systems and Equipment Certification. Establishes software levels and definitions, from Software Level A, in which failure will result in a catastrophic loss, to Software Level E, in which failure has almost no impact. DO-178 also provides information to guide the development process for mission critical software. See also EUROCAE/ED-12B of the same title.

RTCA DO-278—Guidelines for Communication, Navigation, Surveillance, and Air Traffic Management (CNS/ATM) Systems Software Integrity Assurance

SAE-AIR-5121—Software Supportability—An Overview

7.3.3.3 *Data Buses*:

MIL-STD-1553B—Aircraft Internal Time Division Command/Response Multiplex Data Bus, a data bus standard based on using shielded, twisted pair wire as the media. See also North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 3838 (NATO version of MIL-STD-1553B), ARINC Specification 429, and ARINC Specification 629. MIL-STD-1773, Fiber Optics Mechanization of an Aircraft Internal Time Division Command/response Multiplex Data Bus is a fiber optic media version of MIL-STD-1553B. Also, MIL-STD 1760, Interface Standard for Aircraft/Store Electrical Interconnection System, provides a common electrical and digital interface between weapons and aircraft.

ANSI/IEEE Standard 1014-1987—Standard for a Versatile Backplane Bus: VMEbus, describes the VersaModule Eurocard (VME) data bus for multiple microprocessors.

ARINC Specification 429—Covers data buses for analog avionics.

ARINC Specification 629—Covers data buses for digital avionics.

7.3.4 *Links*—The unmanned aircraft's controlling element must maintain secure, reliable communication with the aircraft and with Air Traffic Management (ATM) agencies. Communication with ATM has traditionally been through voice radio, however, with the advent of the Aeronautical Telecommunication Network (ATN), air traffic controllers will be relying increasingly on digital means to communicate instructions to pilots. These command and control communications are typically relayed over narrowband (kilobits/sec) links, while the aircraft's sensor and payload data may require separate, broadband (megabits/sec) links. Communication range requirements for unmanned aircraft range from those operating within visual sight to those beyond visual but within radio line of sight to

those that operate beyond radio line of sight, perhaps employing communication satellites as relays. Maintaining the security of such communication links from interception (compromise of data), denial (jamming of data or control), or hijacking (assumption of control) is key to assuring reliable unmanned aircraft flight.

RTCA DO-136—Universal Air-Ground Digital Communication System Standards

RTCA DO-210—Minimum Operational Performance Standards (MOPS) for Geosynchronous Orbit Aeronautical Mobile Satellite Services (AMSS) Avionics

RTCA DO-238—Human Engineering Guidance for Data Link Systems

SAE-ARP-4102/13—Data Link

SAE-AIR-4271—Handbook of System Data Communications

SAE-ARP-4791—Human Engineering Recommendations for Data Link Systems

SAE-AIR-15532—Data Word and Message Formats

7.3.4.1 *Command & Control and Telemetry*:

NATO STANAG 4586—Standard Interfaces of UAV Control System (UCS) for NATO UAV Interoperability

RTCA DO-219—Minimum Operational Performance Standards for ATC Two-Way Data Link Communications

RTCA DO-254—Design Assurance Guidance for Airborne Electronic Hardware

7.3.4.2 *Data (Payloads/Sensors)*:

SAE-AIR-4911—Requirements Document for Sensor/Video Interconnect Subsystems With Rationale

7.3.4.3 *Link Security and Reliability*:

RTCA DO-167—Airborne Electronics and Electrical Equipment Reliability

RTCA DO-210—Minimum Operational Performance Standards (MOPS) for Geosynchronous Orbit Aeronautical Mobile Satellite Services (AMSS) Avionics

RTCA DO-270—Minimum Aviation System Performance Standards (MASPS) for the Aeronautical Mobile Satellite (R) Service (AMS(R)S) as Used in Aeronautical Data Links

7.3.5 *Other (Avionics)*:

JSSG-2010-2—Crew Systems Crew Station Automation, Information and Control/Display Management Handbook

SAE-AS-8039—Minimum Performance Standard, General Aviation Flight Recorder

8. Test Methods

8.1 *Scope*—The use of individually certified components in a system, while necessary, does not ensure that the functioning of the integrated system is safe and reliable. For this reason, both component and system level testing is required for highly integrated systems such as unmanned aircraft. Although originally oriented toward the testing of manned aircraft, the following standards offer a range of testing guidance applicable to the wide range of unmanned aircraft.

9. Specific Test References

9.1 *FAA AC 90-89A*—Amateur-Built Aircraft and Ultralight Flight Testing Handbook

9.2 *Range Commanders Council Document 323-99*—Range Safety Criteria for Unmanned Air Vehicles

9.3 *Range Commanders Council Supplement to Document 323-99*—Range Safety Criteria for Unmanned Air Vehicles, Rationale and Methodology Supplement

9.4 *RTCA DO-160C*—Environmental Conditions and Test Procedures for Airborne Equipment

9.5 *SAE-ARP-4761*—Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment

10. Keywords

10.1 airframe; airworthiness; aviation; avionics; certification; communication; data link; electromagnetic compatibility; electromagnetic interference; equivalent level of safety; Federal Aviation Administration; flight testing; fuel; materials; navigation; payload; power; propulsion; reliability; sense and avoid; software; standard; UAS; UAV; unmanned aircraft; unmanned aircraft system; unmanned aviation