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Unmanned aircraft systems —

Part 2:
UAS components

Aéronefs sans pilote —

Partie 2: Composants des UAS

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 16, *Unmanned aircraft systems*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The use of unmanned aircraft systems (UAS) or drones, for commercial and recreational purposes has grown in popularity over the last several years. There are many application markets growing rapidly, such as motion pictures and film, security, inspections as well as many uses by organizations to increase public safety. It has been a challenge for operators to use these aircraft due to the lack of regulation and lack of common manufacturing methods a regulator would recognize as safe.

The purpose of this document is to shape a general architecture for the quality and safety of the manufacture of UAS. By addressing the UAS components separately, the document enables manufacturers to focus on the applicable design requirements in order to better promote international trade and basis for future development while enhancing the safety of UAS operations.

Unmanned aircraft systems —

Part 2:
UAS components

1 Scope

This document specifies requirements for ensuring the quality and safety of the design and manufacture of unmanned aircraft systems (UAS) that include unmanned aircraft (UA), remote pilot stations (RPS), datalinks, payloads, and associated support equipment.

This document includes information regarding the unmanned aircraft, any associated remote pilot station (RPS)(s), the command and control links (C2 Link), any other required data links (e.g. payload, traffic management information, vehicle identification) and any other system elements as can be required. This document does not cover passenger carrying UAS or technical requirements for the design and manufacturing for UAS components.

This document does not include equipment considerations unique to compliance with UA traffic management systems.

The document is applicable to the reasonable expected use of a UAS.

This document is applicable:

a) to UAS designed for use where a State aviation authority has determined a Certificate of Airworthiness (C of A) is not required;

b) where a C of A is required, to complement technical standards published by the aviation authority for the purposes of building the certification basis; or

c) as an alternative means of compliance if acceptable to the aviation authority.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6858, *Aircraft — Ground support electrical supplies — General requirements*

IEC 62133 (all parts), *Secondary cells and batteries containing alkaline or other non-acid electrolytes — Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications*

IEC 62368-1, *Audio/video, information and communication technology equipment — Part 1: Safety requirements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
airframe
mechanical structure of an aircraft which typically includes the fuselage, wings and undercarriage and excludes the *propulsion system* (3.8)

3.2
avionics
electronics as applied to aviation which include *propulsion system* (3.8) controls, FCS, navigation, communications, flight recorders, lighting systems, threat detection, fuel systems, electro-optic/infrared (EO/IR) systems, weather radar, performance monitors, and systems that carry out various mission and flight management tasks

3.3
C2 Link
data link between the remotely piloted aircraft and the remote pilot station for the purposes of managing the flight

3.4
controlled airspace
airspace of defined dimensions within which air traffic control service (ATS) is provided in accordance with the airspace classification

Note 1 to entry: Controlled airspace is a generic term which covers ATS airspace classes A, B, C, D and E.

3.5
flight plan
specified information provided to ATS units, relative to an intended flight or portion of a flight of an aircraft

3.6
ground speed
horizontal speed of a UA relative to the ground

3.7
maintenance
performance of tasks required to ensure the *reliability* (3.9) of an aircraft, including any one or combination of overhaul, inspection, replacement, defect rectification, and the embodiment of a modification or repair

3.8
propulsion system
engines and motors using components such as propellers and turbine engines that are necessary for propulsion generation and affect the control or safety of flight.

3.9
reliability
ability of a system or component to function under stated conditions for a specified period of time

3.10
vulnerability
flaw or defect, if exploited, could result in a security or safety compromise

4 Abbreviated terms

C2 Link	command and control link
CA	collision avoidance

C of A	certificate of airworthiness
COTS	commercial off the shelf
C-UAS	counter-UAS
DoD	Department of Defence
E3	electromagnetic environmental effects
EMC	electromagnetic compatibility
EME	electromagnetic environment
EMI	electromagnetic interference
EMSEC	emanations security
EO/IR	electro-optical/infrared
ESC	electronic speed controller
EUROCAE	European Organisation for Civil Aviation Equipment
FCS	flight control system
GNSS	Global Navigation Satellite System
HERF	hazardous electromagnetic radiation to fuel
HERO	hazardous electromagnetic radiation to ordnance
HITL	human in the loop
HUMS	health and usage monitoring systems
ICAO	International Civil Aviation Organization
IMU	inertial measurement unit
RPS	remote pilot station
RTK	real time kinematic
SDLC	software development life cycle
UA	unmanned aircraft
UAS	unmanned aircraft system
UPS	uninterruptable power supply
UV	ultra-violet
VLOS	visual line of sight
VTOL	vertical take-off and landing
WGS	world geodetic system

5 General design requirements for UAS

5.1 General

The systems related to the design of a UAS consist of the:

a) unmanned aircraft;

b) communication systems;

c) mission payloads;

d) RPS;

e) support equipment.

5.2 Function and reliability

5.2.1 Design

The following minimum concepts shall be incorporated in the design to ensure the functionality and reliability of the UAS, wherever possible:

a) simplify the design criteria to reduce the product complexity;

b) identify the components critical to flight safety;

c) ensure the functionality and reliability of the UAS throughout the operational flight envelope, applying safety margins and redundancy for components critical to flight safety;

d) minimise stress to the components and mechanical parts;

e) establish thermal design criteria throughout the components selection, circuit design and structural design to enable reliability over a wide temperature range;

f) conduct an EMI/EMC evaluation and design mitigations for harmful effects of electromagnetic radiation from the operational environment as well as those produced by other components of the UAS;

NOTE Additional information on electromagnetic environmental effects can be found in Annex B.

g) adopt software reliability design and analysis tools;

h) apply environmental protection in the design and materials to limit the environmental effects on components critical to flight safety;

i) apply protections designed to avoid damage to the UAS during the packaging, handling, transportation and storage;

j) establish specific design approach and references to evaluate gust loads, whenever UA configuration leads to extremely severe loads;

k) establish manoeuvre safe operation provisions or limitations, in case of manual commands or semi-automatic commands, to ensure operational flight loads limit to be respected;

l) adopt software reliability design, including cybersecurity requirements, and analysis tools.

5.2.2 Components

The manufacturer shall document the following minimum component reliability for components identified as “critical” in 5.2.1 b):

a) mission time between fatal failures;

b) mean time between failures or failure rate;

c) mean time between maintenance;

d) cumulative failure rate.

5.3 Maintainability and supportability

5.3.1 Design

The UAS design shall ensure:

a) the interchangeability and standardization of parts;

b) that detachable parts cannot be incorrectly assembled;

c) that replaceable parts are readily accessible for maintenance;

d) that diagnostic testing points are readily accessible;

e) there is a method to track parts and components to identify, monitor and promptly act on present or future failures within the UAS;

f) that the maintenance and support requirements document is presented in a clear, consistent and unambiguous manner.

5.3.2 Documentation

The manufacturer shall document the maintenance requirements for components identified as “critical” in 5.2.1 b) and make them available to the operator. The following factors shall be included:

a) mean repair time or repair rate;

b) mean maintenance time;

c) propulsion system replacement time;

d) maintenance schedules and instructions;

e) repair and replace instructions;

f) troubleshooting information;

g) structural inspection intervals and procedures for the UA;

h) servicing information;

i) assembly and disassembly instructions (where applicable);

k) pre-flight and/or post-flight structural integrity checks for UA which are required to be assembled before being operated.

5.3.3 Support

The support requirements shall be documented, and include as a minimum:

a) technical capability requirements of maintenance personnel;

b) list of spare parts (if parts are available to and can be replaced by the operator);

c) list of maintenance supporting tools;

d) if specific maintenance supporting tools are needed, sources of the design, manufacture or procurement organizations for those parts.

5.4 Fatigue durability

The manufacturer shall document the UAS fatigue durability requirements for the expected flight envelope and make them available to the operator. The following factors for components identified as “critical” in 5.2.1 b) shall be included:

a) minimum expected service life;

b) inspections interval;

c) storage life (if applicable).

5.5 Aircraft identification features

Aircraft identification shall be implemented by:

a) the installation of logos or signs, installed on the wings or fuselage, taking into account information required by the local regulatory authorities;

b) equipping the UA with systems that increase conspicuity;

c) equipping the UA with a transponder when operationally intended for flight in airspace where a transponder is required;

d) other systems that assist surveillance, such as electronic identification (E-Id) or automatic dependent surveillance – broadcast (ADS–B), when the UA is designed for flight in airspace where other sensors are required.

5.6 Transportation, storage and packaging

Transport and storage containers or packaging shall be designed specifically for the system.

If transport assembly and disassembly are part of the system design, the design shall, where applicable, consider:

a) protection of foldable structure connections

b) protection of fragile components;

c) protection against adverse environmental conditions;

d) the expected number of reconfigurations in the system life cycle;

e) transportation, storage and packaging as part of the maintenance and fatigue evaluation and damage tolerance analysis.

Storage and transportation requirements shall be included in the operational manual.

6 Aircraft structures

6.1 Overview

UA structural design shall implement the following requirements:

a) airframe shall be designed to ensure flight stability throughout the operational flight envelope with all required equipment and authorized components installed;

b) airframe design shall assure structural integrity without detrimental deformation throughout the operational envelope (flight and ground operations);

c) airframe design shall meet the UA operating environmental conditions expected in service (e.g. temperature, electromagnetic conditions, humidity, altitude);

d) the material used in the manufacture of the airframe shall be consistent in strength/durability with the design values;

e) serviceable components shall be identified in the operator's manual;

f) airframe shall be designed to ensure the vibration and aero-elastic effects of mounted components do not adversely affect the stability of the UA throughout the operational envelope;

g) part of the structure shall include lightning protection, if operations in and around lightning conditions are within the design criteria;

h) structural testing shall be carried out on airframe components that are critical to the safety of flight;

i) The manufacturing processes and materials used in the construction of the UA shall result in known and reproducible structural properties.

For rotorcraft, these requirements are also applicable to the vertical lifting elements and components (e.g. rotors, blades, transmissions, drive shafts, gearboxes).

6.2 Damage tolerance assessment

Damage tolerance assessment shall include inspections or other procedures developed and implemented to prevent catastrophic structural failures due to foreseeable causes of strength degradation, including:

a) fatigue;

b) corrosion;

c) manufacturing defects, including material variability;

d) accidental damage.

For structural components where a damage tolerance assessment is impractical, an analysis shall be completed and supported by test evidence that the components maintain design integrity throughout the service life of the UA without detectable damage.

6.3 UA construction

Manufacturing processes and materials used in the construction of components identified as "critical" in 5.2.1 b) shall ensure the functionality of the components is maintained over the service life of the UA.

6.4 Moving parts

The design and use of moving parts that cannot be replaced and are identified as "critical" in 5.2.1 b) (other than vertical lifting elements and components in rotorcrafts included in 6.1), shall ensure the parts can sustain the functionality over the service life of the UA.

6.5 Attached parts

For all parts identified as "critical" in 5.2.1 b) that are attached or mounted to the airframe:

a) threaded parts shall have a locking mechanism;

b) quick release parts shall meet the mechanical precision, strength, and fatigue resistance requirements to sustain functionality over the service life of the UA.

7 Propulsion

7.1 Propulsion risk management

Risk management of propulsion system shall consider reliability, maintainability, testability, supportability, safety, durability and environmental adaptability.

Where possible predictive failure systems should be implemented to reduce the risk of inflight failure.

In the event a single component of the propulsion system fails on a multi-rotor UA, the UA should be able to maintain a stable flight attitude to landing.

7.2 Engines and motors

7.2.1 General requirements

Operational limitations shall be documented and include:

a) revolutions per minute (RPM);

b) sustainable time under largest consecutive power or take-off power (under both critical height and sea level);

c) battery power requirements or other specification;

d) for combustion engines:

   1) intake pressure;

   2) grade of fuel requirements.

7.2.2 Mounting and installation

Mounting and installation shall:

a) be in conformance with design requirements;

b) be convenient for checking, repairing, installing, dismantling and updating;

c) ensure the engine compartment has sufficient margin to accommodate changes in engine characteristics due to heating;

d) not adversely affect the structure of the airframe;

e) not include the engine or motor as a part of the airframe's load supporting system;

f) ensure the stability of the UA is not affected by engine's vibration;

g) be isolated by fire-resistant bulkhead or material.

7.2.3 Combustion engines

7.2.3.1 Power

In addition to normal flight requirements, engine power output shall be sufficient to enable generators (if so equipped) to supply electrical power to all flight critical equipment and recharge batteries.

7.2.3.2 Lubrication

The oil system shall maintain oil temperature, pressure and consumption limits within normal operating range during all allowable flight conditions.

7.2.3.3 Fuel system

The fuel system shall provide the necessary fuel flow at the necessary conditions required by the engine(s) throughout the operational envelope.

Fuel tanks and fuel lines must be protected against wear from vibrations.

The fuel tank shall ensure:

a) the pressurization system meets the requirements for aircraft max allowable altitude;

b) fuel is not syphoned or spilled during any phase of flight within the approved operational envelope;

c) fuel gauges are included to measure the quantity of fuel remaining in the fuel tanks;

d) the fuel vent functions properly.

7.2.4 Electric motors

Temperature sensors shall be used to monitor flight critical systems.

7.2.5 Electronic speed controller (ESC) requirements

The following specifications of the ESC shall be clearly defined:

a) continuous and maximum output voltage;

b) continuous and maximum output current;

c) operable temperature;

d) fault protection systems.

7.3 Thrust mechanisms

7.3.1 Propellers and rotors

7.3.1.1 Precautions

The manufacturer shall ensure rotating parts do not contact other parts of the airframe.

Rotating parts shall be protected from or yield on impact with an object.

To prevent rotors from contacting people or objects, rotor guards should be incorporated on rotorcraft design.

7.3.1.2 Resonance

The operational and harmonic frequency of the rotor or propeller shall not be the same as the natural frequency of the airframe.

Rotorcraft shall not oscillate on the ground with the rotors/fans turning.

7.3.1.3 Connections

The maximum number of mounts and dismounts of the propeller or rotor before replacement is required shall be defined and published in the operator's manual.

7.3.2 Turbine and fans

a) Turbine and fans shall be constructed of material that resists corrosion.

b) When an adjustable outlet blade is incorporated, the outlet design shall prevent damage that may be caused by airflow-housing-induced vibrations.

c) When ducted fans are incorporated in the design, gyroscopic torque shall be minimised.

d) Dynamic failures of the turbine or fans shall be contained.

8 Electrical systems

8.1 General

The electrical systems for the UAS include airborne electrical systems and ground electrical systems.

A master switch for disconnection of all electrical power may be associated with an RPS if it has been shown that no adverse effects to the RPS or other UAS components are realized if it is used.

8.2 Electrical safety

Circuitry in the UA shall conform to IEC 62368-1 if the UA voltage is over 60 V d.c.

Electrical connections shall be secure and conform to the appropriate standard for type of connection used.

8.3 Airborne electrical systems

Airborne electrical systems shall:

a) provide the necessary voltage and current to the UA throughout the operational envelope;

b) include overload protection devices (i.e. fuses or circuit breakers).

8.4 Ground electrical systems

8.4.1 UAS electrical components on the ground

Electrical systems used to power UAS components on the ground shall meet all power utilization requirements and the requirements in ISO 6858.

8.4.2 RPS power system

The RPS power system shall power all the flight critical systems (at maximum power rating) without overloading any circuit breakers.

Flight critical systems should have redundant power supplies or uninterruptable power supplies (UPS).

If a redundant power supply or UPS system is used, an alert shall be provided to the remote pilot if:

a) the power to the RPS is being provided by a redundant power supply or UPS; and

b) the redundant power supply or UPS system fails under otherwise normal operating conditions.

8.4.3 Labelling

All ground power facilities shall be fitted with a metal or pressure-sensitive data plate displaying the information in IEC 62368-1.

9 Energy sources

9.1 Batteries

9.1.1 General

The battery installation shall be able to withstand the applicable inertial loads.

Nickel or Lithium batteries used as part of a UAS shall conform to the IEC 62133 series.

Information concerning battery storage, operation, handling, maintenance, safety limitations and environmental precautions shall be provided in the operator's manual.

9.1.2 Protective measures

The battery shall have the following protective measures:

a) a high and low voltage protection;

b) an overcharge prevention;

c) a thermal protection;

d) an alert for fault and abnormal situations.

The battery shall stop charging if a protection function fails.

9.1.3 Precautions

In case of damage caused by shock, drop, impact, exposure to moisture or short circuit, the battery shall be:

a) protected against fire or explosion;

b) resistant to leakage and cracking

9.2 Combustible fuels

When using combustible fuels, the inclusion of a fire suppression system in the design of the UA shall be considered.

9.3 Fuel cells

9.3.1 General requirements

a) Surfaces of fuel cell system shall be clean, with no mechanical damage, surface cracks, stains, visible deformation or tarnishing of the contact cables.

b) Communication interface, output interface and user interface of fuel cell system shall be marked clearly.

c) The components and connections of the fuel cell system shall be secure and be able to withstand the applicable inertial loads.

d) The positive and negative connector of a fuel cell system shall be marked clearly and connected easily.

e) The fill and drain points of reactant in fuel cell system shall be marked clearly.

f) Operating temperature, humidity, pressure and other limiting factors shall be specified in the operator's manual.

g) Information concerning fuel cell storage, operation, handling, maintenance, safety limitations and environmental precautions shall be provided in the operator´s manual.

NOTE Additional information on fuel cells can be found in the IEC 62282 series.

9.3.2 General safety requirements

a) There shall be both automatic and manual containment measures in the event of a leak in the fuel cell(s).

b) Measures to avoid touching or closing of components of the fuel cell system at high temperatures shall be incorporated in the design of the UA.

9.3.3 Protective measures

The fuel cell shall have the following protective measures:

a) a high and low voltage protection;

b) alert for fault and abnormal situation;

c) thermal and overpressure protection.

10 Equipment

10.1 Avionic equipment (general)

Avionics equipment shall:

a) function in all intended operating flight environments and conditions;

b) be installed according to limitations specified for that equipment

c) have a built-in test function that operates before and during the flight;

d) have insulated on-board data buses with sufficient redundancy, reliability, and integrity to meet system safety and flight-critical requirements;

e) have any operating limitations documented in the operator's manual.

A functional failure or functional degradation of the avionics system shall not affect flight safety.

10.2 Flight control system (FCS)

10.2.1 General requirement

The FCS shall include:

a) a built-in test function that operates before and during the flight;

b) real-time detection of power supply faults;

c) an indication of flight controller firmware version.

The FCS shall be capable of sustaining stabilized flight in case of lost C2 Link with the RPS.

Latency in the FCS response shall not affect the stability of the UA.

Transitions between automated and manual modes of flight control shall not affect the stability of the UA.

The system shall limit the angle of attack or bank angle to prevent stalling.

Automated flight control modes shall include command guidance and control settings for maintaining at least the following functions:

— altitude;

— course;

— speed (air or ground);

— position hold (for rotorcraft).

In multi-rotor UA, the FCS shall be capable of providing sufficient manoeuvrability for controlled flight in case of engine or motor failure.

10.2.2 Flight control hardware

The flight control hardware controls the engines, motors, and control surfaces to implement the flight control function. The FCS hardware shall:

a) support basic control functions and methods;

b) maintain position control accuracy;

c) maintain velocity control accuracy;

d) maintain attitude control accuracy;

e) maintain stability of the UA;

f) enable selection of the various flight modes, if more than one flight mode is available;

g) support pre-flight testing of the flight controls;

h) be EMI resistant.

Any FCS shall ensure redundancy of hardware, sensors, power supply and structure, if required.

10.2.3 Flight control software

Flight control software is the on-board navigation, guidance and control system to control the speed, altitude, position and flight path. The flight control software shall:

a) be adaptable and upgradable;

b) provide data logging and management functions;

c) have a power on built-in test function and fault detection and analysis functions;

d) include system fault tolerance and alert when faults are detected;

e) continue to provide navigational guidance to the UA in the event of a lost C2 Link.

f) support geo-limitation systems, if installed;

g) enable an emergency landing, if required.

10.2.4 Course accuracy

The system shall maintain course accuracy, as defined by the manufacturer, under the following conditions:

a) wind velocity from all azimuths;

b) gusts;

c) manual command of the UA controls.

10.2.5 Airspeed

10.2.5.1 Fixed wing UA

The system shall specify whether the airspeed being maintained is ground speed as derived from GNSS, or indicated airspeed as derived from pitot static sources.

In steady state, the automatic FCS shall maintain a designated airspeed.

10.2.5.2 Rotorcraft

Rotorcraft shall have hold modes for either airspeed, ground speed or both.

In an automatic mode, an FCS shall maintain a designated speed:

a) in level flight;

b) when a ground speed is able to be maintained in the wind conditions;

c) when an airspeed hold mode function is engaged.

If a ground speed cannot be maintained due to wind conditions and an airspeed hold mode is available, the speed hold controller shall engage the airspeed hold mode and use the airspeed as the control reference signal or inhibit the engagement of a ground speed hold mode.

When a position hold mode is selected, the FCS shall maintain the aircraft in a longitudinal, lateral and vertical position.

The pilot shall be alerted when the aircraft can no longer maintain a groundspeed and has switched to airspeed hold.

10.3 Flight control actuators

The FCS shall be resistant to EMI.

The flight control actuator characteristics shall:

a) be sufficient to actuate flight control surfaces within the expected flight loads;

b) have a built-in test function, indicating both that the test is in progress and the results;

c) have an alert indicating the servo is approaching functional limits (including rotation range, speed limit and maximum torque, etc.).

10.4 Diagnostics

In all intended operating environments, on-board avionics diagnostics systems shall alert for:

a) evaluated faults;

b) failures of a diagnostics system.

False alarms shall be limited to the maximum extent possible without compromising flight safety.

10.5 Navigation systems

10.5.1 General

The UAS shall have at least one navigation system when flown out of doors.

UA equipped with a geo-limitation system shall have a Global Navigation Satellite System (GNSS) based navigation system.

10.5.2 Global Navigation Satellite System (GNSS) receiver

The GNSS receiver implemented in the UA receives and digitally processes the signals to provide position, velocity and time. The following functions shall be included in GNSS receivers:

a) support for multiple satellite systems, if necessary;

b) indicators for signal quality, number of satellites being received and position accuracy;

c) differential positioning (if included as a design requirement);

d) anti-interference capability.

10.5.3 Real time kinematic (RTK) augmentation

The RTK satellite navigation may achieve real-time corrections with up to centimetre-level accuracy for the navigation sensor error (NSE) using measurements of the phase of the signal's carrier wave. RTK systems shall have the following specifications:

a) support for multi-mode and multi-channel systems;

b) a clearly defined positioning and measurement accuracy;

c) a system interface compatible with all designed or authorized RPS.

A multi antenna RTK may also be used to provide heading and attitude measurement.

10.5.4 Inertial measurement unit (IMU)

An IMU is an electronic device that measures and reports aircraft acceleration and angular rate. When included in the design, the IMU shall meet the following requirements:

a) support for power-on built-in tests, fault diagnosis and calibration functions;

b) contain a fault tolerant algorithm to identify failing sensors and suppress that data.

The following IMU characteristics shall be clearly defined in the operator's manual:

— operational limitations (i.e. temperature, air pressure humidity limits, etc.);

— measurement range, accuracy, and error tolerance.

10.5.5 Magnetic compass

The function of a magnetic compass is to measure the magnetic flux of the Earth and determine the orientation of the UA. When included in the design, the magnetic compass shall:

a) be resistant to interference and include warnings in the event interference is detected;

b) ensure the installation location does not affect the accuracy of the compass;

c) have a power-on built-in test, fault diagnosis and gain calibration functions.

The following characteristics of the magnetic compass shall be clearly defined in the operator's manual:

— operating environment;

— measurement range, accuracy, error tolerance and upper bound of the temperature bias;

— compensation for installation error, after calibration, any residual errors.

10.6 Attitude sensors

10.6.1 Altimeter

The UA shall have one or more altitude measurement devices installed. As a minimum, one of the following altitudes references shall be provided:

a) altitude above mean sea level (MSL);

b) altitude above ground level (AGL);

c) height above ellipsoid based on WGS-84 coordinate system;

d) if operating in VLOS, height above take-off point.

When more than one altitude reference is available, an indication as to which reference is being used shall be displayed at the RPS.

If a barometric based altimeter is not installed, conversion to a barometric altitude display shall be provided for flight within controlled airspace.

10.6.2 Airspeed sensor

An airspeed sensor measures the difference in pressure between the air around the craft and the increased pressure caused by motion through the air mass. At least one of the following airspeeds shall be provided:

a) indicated airspeed;

b) calibrated airspeed;

c) true airspeed.

The airspeed sensor shall:

— have a reliable water drainage system;

— be airtight, except for the measurement vent;

— ensure the static pressure system accounts for any measurement error.

If installed, the status of the icing detection system shall be displayed at the RPS.

10.6.3 Optical sensor

Optical sensors may be used for navigation (where regulations permit) and positioning. The following information shall be included in the operator's manual:

a) blind zones;

b) environmental limitations (e.g. rain, fog, external lighting conditions);

c) resolution quality;

d) exposure, gain and focal length ranges.

10.7 Hardware and software redundancy

Redundancy should be included in both hardware and software systems that affect flight safety.

Where the size, weight and power of the UA allow, critical components for flight safety should ensure redundancy is included in the:

a) flight control computer;

b) navigation system;

c) power supply system;

d) flight control actuators;

e) propulsion for multi-rotor craft;

f) communication systems (e.g. C2 Link).

UAS software should have the ability to retain the flight data in order to prevent data loss due to system errors or system failures.

10.8 Failure modes

When a UA encounters faults in communications, GNSS, flight control surfaces, engines, motors, propellers, undercarriages (for UA with retractable landing gear) or power supplies, the UA shall automatically provide a warning to the remote pilot at the RPS that the UA is in failure mode as soon as the fault is detected.

The operator's manual shall detail the UA response to failures, such as:

a) when the C2 Link is lost;

b) failure of a flight control component;

c) when the engine, GNSS or main power fails and the UA is unable to return to home;

d) when a parachute or air bag would activate (if installed);

e) for multi-rotorcraft, the UA response in the event of a single motor or rotor failure.

The operational manual shall explain how to locate the position of a UA installed with GNSS if the UA was unable to return to home.

Failure of any single sensor, connection, processor, or display unit shall not result in loss of safety-critical data or display unsafe or misleading data.

11 C2 Link

11.1 Performance and design

The specific performance parameters of the UAS data link shall be determined according to the operational requirements and the type of the UAS and provided in the operator´s manual.

The design of the data link shall mitigate co-channel and adjacent channel interference with other users of the spectrum.

The data link shall ensure a reliable connection and the desired data rate at the maximum operating range of the UA taking account of degradation of the signal in space in the proposed operational scenario.

Latencies in the C2 Link shall not affect the flight safety of the UA.

There shall be an alert at the RPS for any loss of the C2 Link.

EMI/EME considerations in Annex B shall be included in the design criteria.

11.2 Antenna module design

The antenna design shall ensure:

a) the influence of the body of the UA on the antenna pattern is minimised;

b) the mechanical and electrical properties of feeders are not stressed during flight;

c) the radome (if included) is made of low electromagnetic loss material;

d) alerts are provided at the RPS when the UA is approaching masking attitudes in order to prevent a total loss of C2 Link.

11.3 Operations

The C2 Link shall:

a) be able to maintain a bi-directional data transmission between the UA and the RPS;

b) provide usable signal reliability between the UA and the RPS with the integrated or relay equipment;

c) have sufficient bandwidth for the remote pilot to maintain control of the UA at all times;

d) prioritize transmitting flight critical data above all other data;

e) transmit and receive data in all intended operating environments and conditions;

f) provide an automated process to reacquire the link in case of C2 Link loss;

g) provide for safe flight in all operating environments, weather conditions, and aircraft manoeuvres;

h) not affect the flight safety of the UA due to latencies.

11.4 Monitoring

a) The integrity of the C2 Link (uplink, downlink) shall be continuously monitored at a refresh rate consistent with safe operation.

b) The signal strength of the C2 Link should be displayable to the remote pilot.

c) Warning cues should be provided to the remote pilot if the C2 Link is degrading to minimise the potential for C2 Link loss.

11.5 Protocol

The RPS to UA C2 Link protocol shall provide separation between flight critical data and non-flight critical data.

11.6 Data features

11.6.1 General

Data can be transmitted to provide a myriad of control functions to the UA as well as system and payload information to and from the UA.

11.6.2 UA status data

The data regarding UA status shall include:

a) location, including latitude and longitude and altitude (AGL, MSL or height above take-off point);

b) horizontal speed, vertical speed, and heading;

c) UA attitude;

d) the status of remaining energy or fuel;

e) the status of other on-board equipment deemed safety critical by the manufacturer.

11.6.3 Delay requirements

a) Delays or latencies in transmission or reception shall be included in the operator's manual.

b) Delays or latencies in UA control data shall be accounted for in determining the operational specifications of the UA for safety critical functions such as take-off and landing operations.

11.7 Reliability requirements

The data link transmitting flight critical information to the UA shall be prioritized above telemetry and payload data link reliability. All data elements shall:

a) identify and account for interference;

b) expeditiously acquire and synchronise with a secondary data link in the event of a loss of a previously operational data link;

c) ensure a safety margin is included when determining the distance and rate requirements;

d) mitigate co-channel and adjacent channel interference, taking into account the requirements of the applicable radio regulations.

11.8 Security requirements

The privacy and integrity requirements of the data carried by the data link shall ensure:

a) the C2 Link is encoded in a manner to be unique between the RPS and the UA;

b) the C2 Link is designed to prevent remote data from being intercepted or spoofed;

c) the C2 Link is designed to prevent UA from being hijacked.

12 Remote pilot station

12.1 General

This clause applies to any configuration of an RPS, such as stationary, vehicle-mounted, portable, or handheld.

12.2 Features

12.2.1 General

The RPS shall:

a) control, display and record flight paths and UA parameters and other telemetry information;

b) control, display, and record UA payload information;

c) record radio and intercom transmissions, if so equipped.

12.2.2 Data monitoring systems requirements

The remote pilot (and the operator, if desired) shall be able to monitor the UA performance data in real-time.

UA operational data shall be capable of being retained for post-flight analysis.

Data systems shall include provisions for:

a) controlling user permissions;

b) storage, management and analysis;

12.3 Design requirements

12.3.1 System

a) The RPS shall be reliable enough to ensure control of the UA and include displays to provide safety critical flight information, to include flight status and warning information, to the remote pilot.

b) Instructions to be transmitted by the RPS that could adversely affect the safety of flight shall have corresponding safety protection measures to ensure erroneous or false commands are not sent to the UA.

c) Flight and mission parameters shall be displayed in graphical and/or numerical form.

d) UA flight path and programmed route shall be displayed on a map background, if one is available.

12.3.2 Structure

The RPS shall:

a) be easy to operate, use, install and maintain;

b) ensure that the equipment meets the requirements of environmental adaptability, mobility, and transportability;

c) account for heat dissipation, and meet the environmental conditions such as vibration, impact, and other fatigue induced factors.

RPS using off the shelf devices (such as laptops or cell phones) can be used as displays, recording devices, or control devices, provided those devices conform to the data link requirements in Clause 11.

12.3.3 Human factors engineering and ergonomics design

RPS shall be designed:

a) following the recognition of human factors engineering principles applicable to the methods in which they are intended to be operated;

b) to enable the remote pilot to monitor and control the UA without undue discomfort or fatigue;

c) to reduce the potential for, and minimise the consequences of, a remote pilot induced error.

NOTE Guidance material on the application of human factors principles can be found in the International Civil Aviation Organization's (ICAO) Human Factors Training Manual (ICAO Doc 9683).

12.4 Functional requirements

12.4.1 Mission planning

Mission planning based on flight performance, mission needs, and application environment (including geography, weather, electromagnetics, etc.) is a task to be accomplished prior to each flight. The RPS shall incorporate as many of the mission planning tools as possible.

12.4.2 Data link control

Where the UAS remote pilot is required to select data link configuration, controls shall be available to automatically or manually:

a) select the appropriate data link, if there are multiple data links available;

b) select the appropriate band, if there is more than one working band available;

c) adjust link parameters;

d) track the real-time position of the UA.

12.4.3 Flight Control Commands

The RPS shall be capable of transmitting the following flight control commands to the UA:

a) heading;

b) horizontal speed;

c) vertical speed;

d) altitude;

e) navigational control.

12.5 Displays

12.5.1 Instrumentation

The following system information shall be displayed:

a) aircraft status;

b) environmental (e.g. wind, temperature, weather (if available));

c) datalink status;

d) flight parameters (attitude, altitude, heading, air or ground speed, etc.);

e) propulsion system data (engine health status - rpm, applicable temperatures, oil pressure, etc.);

f) remaining fuel or battery life;

g) aircraft location (on a moving map, if so equipped).

12.5.2 Readability

Flight displays and interfaces shall be fully readable in all intended operating environments and conditions. Any symbols used to present critical flight information shall be easily understandable.

Flight data display may conform to Electronic Flight Displays FAA Advisory Circular AC No: 25-11B or similar standard.

12.5.3 Accuracy

Flight-critical information being displayed shall be accurate and refresh rate shall be fast enough to not hinder safe flight in all intended operating environments and conditions.

12.5.4 Warnings, cautions, and advisories

Any relevant cautions, warnings, or advisories regarding aircraft operation shall:

a) be organized and presented in a prioritized system that is accessible and easily readable by the remote pilot in all intended operating environments and conditions;

b) be designed to minimise the occurrence of false and nuisance alerts;

c) have an alert inhibit function to prevent the presentation of an alert that is inappropriate or unnecessary for a particular phase of operation;

d) provide the flight crew with the information needed to identify non-normal operation or UA system conditions, and determine the appropriate actions, if any;

e) have a low battery, fuel or energy warning to alert the remote pilot that the energy supply has discharged or depleted to a level that requires immediate recovery actions.

12.5.5 Display/interface failures

The aircraft shall be capable of automatic flight in the event of a failure in avionics interface or display systems that hinders control of the aircraft by the remote pilot.

12.5.6 Track and parameter display

For automated flight or flight beyond visual line of sight of the remote pilot, the display of tracks and flight parameters shall:

a) be displayed on a map with a background;

b) include at least the position, height (MSL, AGL or height above take-off point), speed (vertical speed and horizontal speed), attitude (heading, pitching angle, bank angle), and power status (residual power value) of the UA;

c) provide a visual alert when the UA is in a critical or dangerous flight parameter, which should be accompanied by an aural alarm.

12.5.7 C2 Link status display

The C2 Link operating status display shall meet the following requirements:

a) the status and signal strength of the C2 Link shall be displayed, preferably in a graphical manner;

b) when the working status is abnormal, there shall be an alert displayed, which may be accompanied by an aural alarm.

12.5.8 Telemetry parameter record

The received UA telemetry parameters and positioning data shall be recorded.

12.6 Performance requirements

12.6.1 Environmental adaptability

The equipment shall be designed to accommodate the environmental conditions in which it is intended to operate. As a minimum, the following factors shall be addressed/considered:

a) temperature;

b) atmospheric pressure;

c) humidity;

d) impact;

e) vibration;

f) lightning;

g) rain;

h) icing;

i) mildew;

j) salt spray;

k) sand and dust;

l) sheltered from wind;

m) noise level.

12.6.2 Reliability

Technical measures to improve reliability shall include the following:

a) select mature design solutions and components and fully consider inheritance;

b) meet the functional requirements of the product with the fewest components and parts as possible, and reduce the complexity of the equipment;

c) include error-tolerant design of circuits and software, to avoid the effects of transient processes and accidental errors or failures;

d) include thermal design, anti-vibration design and electromagnetic compatibility design, to reduce the impact of environmental effects. Additional information on electromagnetic environmental effects can be found in Annex B.

12.7 Safety

RPS safety measures shall include:

a) protection measures against electrical overload, corona discharge and electrical breakdown, as well as protection against electrostatic discharge;

b) connectors and electronic modules with built-in design features, such as specified keys, to prevent incorrect or inadvertent connections;

c) grounding of the RPS chassis and any equipment affixed to the RPS;

d) an ability to terminate the power supply quickly and easily;

e) if enclosed, fire-resistant material, firefighting equipment and lightning protection measures.

12.8 Collision avoidance (CA) systems

The RPS shall provide the remote pilot with an interface to view and interact with CA system alerts, messages, and system configuration, if the UA is equipped with a CA system.

13 Payload

13.1 General requirements

This clause consists of any additional items that can be carried by or attached to the UA that contributes to completion of the designated mission and interfaces with UA components not used or intended to be used in operating or controlling an aircraft in flight and not part of an airframe, engine, motor or propeller. This clause is not intended to address cargo delivery operations, unless there is a delivery or release mechanism that is managed by a component resident on the UA.

The payload shall:

— be compatible with the UA's electrical circuits;

— be compatible with other UAS frequencies on-board or in ground systems;

— be electromagnetically compatible with other UA components;

— be mounted or positioned to ensure the UA's flying qualities will not be affected;

— be able to be disconnected from flight critical electrical distribution;

— be automatically disconnected from main power supply in the event of a low battery warning, unless the payload is critical to flight safety.

The payload shall not:

— cause the UA to exceed the maximum take-off weight;

— affect the take-off, flight, and landing safety of the UA;

— adversely affect the stability or control of the UA, whether functioning properly or improperly.

13.2 Safety marking

The necessary marking shall be used for parts of the payload that:

a) cause mechanical, electrical, or electromagnetic failures;

b) contain or cause exposure to toxic substances;

c) generate heat, radiation or noise that could injure ground personnel;

d) remind the remote flight crew and maintenance personnel to take corresponding protective measures.

13.3 Wiring design

The installation clearance shall not cause damage to cables or wires during installation or operation.

The cable shield, wiring and grounding shall be properly designed according to the spectrum and voltage level of the transmitted signal.

13.4 Payload power supply

The payload power requirements shall be:

a) compatible with the aircraft power characteristics;

b) equipped with reverse polarity protection;

c) designed with electrical overload and electrical protection;

d) specified in the operator's manual.

13.5 Storage requirement

Storage requirements shall be included in the operator's manual or a manual provided by the payload manufacturer.

14 Airworthiness

14.1 Documentation

14.1.1 Instructions

Work and inspection instructions shall be defined, documented, and implemented for all critical manufacturing processes. Quantitative quality criteria shall be used for product acceptance at all levels of design and manufacturing processes.

14.1.2 Manuals and handbooks

The manufacturer shall document all data and instructions related to the operation and operational limits of the UA as well as the maintenance of the UAS equipment in an operator's manual.

14.1.3 Procedural changes

Changes in design, operations, maintenance, transportation, or storage procedures shall not adversely affect the aircraft's ability to safely fly in all intended operating environments and conditions.

14.2 Composition of an operator's manual

14.2.1 Technical specifications

The technical specifications, operator's manual, inspection and maintenance instructions and drawings, required spare parts and special tools shall be documented by the manufacturer and provided to the users.

The technical specifications provided to the user shall include the characteristics, listed in 14.2.2 to 14.2.6, as a minimum.

14.2.2 Flight performance

a) Maximum operating speed

b) Maximum range/best loiter speed

c) Best glide speed, glide ratio and/or autorotation speed (as applicable);

d) Take-off and landing speed

e) Service ceiling

f) Maximum expected flight endurance

g) Maximum expected flight range

h) Manoeuvring limitations

i) Take-off and landing distance, if applicable

14.2.3 Aircraft weights

a) Maximum take-off weight

b) Maximum payload weight (if the aircraft can be configured with alternate or additional payloads)

c) Empty weight

d) Centre of gravity calculation charts

14.2.4 Flight control accuracy

a) Attitude

b) Heading

c) Altitude

d) Speed

e) Course

f) Position (as derived from guidance and navigational systems)

14.2.5 Dimensions

a) Length

b) Height

c) Wing span for fixed wing

d) Distance between opposite rotors for multi-rotorcraft

14.2.6 Atmospheric and other environments adaptability

Operational limitations for a minimum of the following conditions shall be documented in the operator's manual (when the UAS is designed and manufactured for such a purpose):

a) icing;

b) rain;

c) winds, crosswinds and gusts;

d) operating temperatures and humidity;

e) dust resistance;

f) harsh environments (e.g. corrosive, chemical, saline fog, pollution).

14.3 Electromagnetic compatibility considerations

The UAS shall be electromagnetic compatible. The electro-magnetic compatibility shall include the EMI and electromagnetic sensitivity (EMS) requirements for all equipment and subsystems mutually.

Electromagnetic radiation sources shall not pose any danger to personnel or fuels.

Manuals shall include safety guidelines on the distance between on-board and off-board radiation sources to personnel and fuel sources.

UAS shall be electrically grounded.

The UAS should incorporate appropriate lightning protection measures.

Additional information on electromagnetic environmental effects can be found in Annex B.

14.4 Noise

Noise levels for components such as engines, motors, rotors and propellers shall be documented if the noise levels exceed thresholds that would potentially cause hearing loss or required hearing protection when operated.

If noise levels exceed thresholds that would potentially cause hearing loss or required hearing protection when operated:

a) a requirement for hearing protection shall be included in the operator's manual;

b) a safe operational distance for which hearing protection is not required shall be specified.

14.5 Built-in test and monitoring

Built-in test equipment shall alert the remote flight crew of the status of all flight-critical functions.

Built-in test equipment shall indicate which system triggered an alert.

14.6 System safety program

14.6.1 Selection of design materials

Materials shall be selected and implemented with a focus on the following conditions:

a) criticality of the material in the aircraft's design;

b) environmental extremes;

c) material reparability;

d) occupational safety;

e) minimization of hazardous waste;

f) material life (e.g. corrosion resistance, UV tolerance).

14.6.2 Properties and processes

14.6.2.1 Load limits

Load limits shall be defined as the maximum loads anticipated on the aircraft throughout its service life. All loads within defined limits shall not adversely affect the safe operation of any component of the aircraft in any intended operating environment or condition.

The following shall be considered when defining load limits:

a) centre of gravity (longitudinal, lateral, and vertical, if required);

b) materials of load limits;

c) strength of aircraft materials;

d) weight of aircraft;

e) payload mounting location;

f) propulsion forces;

g) repeated loads;

h) stresses and strains from flight/airflow on the UA, and payloads;

i) potential stresses from intended environment/conditions;

j) dangerous goods.

14.6.2.2 Load testing

The minimum, maximum, and most common load arrangements shall be assessed to ensure flight safety in all intended operating environments and conditions.

Load testing shall be conducted using realistic flight and load conditions.

14.6.3 Mass properties

14.6.3.1 Evaluation of mass properties

The mass properties of the aircraft (in its most current configuration) shall be documented and evaluated to ensure they allow for safe flight in all intended operating environments and conditions.

14.6.3.2 Centre of gravity

The aircraft's centre of gravity (and its effects on flight) shall be assessed to ensure safe flight can be maintained in all intended operating environments and conditions. Changes to the centre of gravity due to fuel usage, loading, or any other variable condition shall also be considered and included in this assessment.

14.6.4 Corrosion

Measures designed to protect against corrosion or any other long-term deterioration of aircraft components shall remain effective through the aircraft's intended service life.

14.6.5 Material limitations

All limitations to the following aircraft material properties shall be defined and documented:

a) load bearing capabilities;

b) damage tolerance;

c) fire resistance.

All limitations shall not hinder safe flight in all intended operating conditions and environments.

14.6.6 Fire hazards

The design of aircraft systems and structures shall account for potential fire hazards, and work to mitigate their effects on safe operation. As a minimum, the aircraft shall:

a) minimise the potential sources of ignition where flammable aspects of the design (fuels, vapours, etc.) are involved;

b) ensure that safety and flight-critical components can withstand heat and fire to a level determined by the vehicle's size and intended use;

c) properly ventilate and drain flammable by-products of aircraft systems;

d) ensure that any aircraft process that involves an ignition is conducted safely, and any risk of extraneous combustion is minimised.

14.6.7 Equipment separation

Separation of the following components shall be sufficient to eliminate the risk of accidental ignition due to proximity to each other:

a) oxidizers;

b) flammable fluid systems;

c) engine or motor components that emit heat;

d) electrical components.

15 UAS software

15.1 Software architecture and design

Software standards shall be applied to any system related to the operation of the UAS. The software may be contained in the RPS, on-board the aircraft or interface with payload control.

UAS software architecture shall be as secure as possible. Whilst, at present, no usable system is 100 % safe and secure, it is important that the architecture is designed to balance between risks and resources with a default position of 'least privilege', 'airworthiness' and 'public safety'.

Software risks shall be identified, assessed, mitigated and monitored as part of an established risk management process (Annex A).

15.2 Safety

UAS software systems shall be developed using a development life cycle process which ensures that safety assurance activities are an integral part of the development effort and part of an ongoing, closed loop risk management process.

15.3 Security

UAS software systems shall be developed using a development life cycle process which ensures that security assurance activities are an integral part of the development effort and as part of an ongoing, closed loop risk management process.

15.4 Software compliance

RPS software shall reflect the intents and goals of a selected operational response to any expected context that an RPS must handle. It is important to maintain a consistent trail of software development that clearly defines the various levels of software construction, from use cases to component specifications. To manage this process, the following apply.

a) Use cases shall reflect the most complete possible set of expected operational scenarios for an RPS. They must also outline assumptions made for the episodes of each use case in order to verify feasibility of every assumption and responses to detected anomalies.

b) Object and process specifications derived from these use cases must verify compliance with the expected outcomes of every episode in the corresponding use case.

c) Code derived from them must demonstrate its behaviours to be compliant with the specification and their expected outcomes.

15.5 Software development life cycle

A software development life cycle (SDLC) is a framework that defines the process used by organizations to build an application from its inception to its decommission.

UAS software systems should be developed using a software development lifecycle process as detailed in ISO/IEC/IEEE 12207 and encompassing the safety and security elements specific to UAS as detailed in this document.

16 Other considerations

16.1 Ground equipment

Ground support equipment, including maintenance equipment, catapults, netting, cables or hand launchers, shall be:

a) designed to meet the operational requirements of the UA;

b) be reliable, safe to operate and include caution or warning signs where appropriate to prevent injury to personnel involved with the UA operation or other spectators;