13 Appendix C - Technical documentation of the UAS

The below UAS description follows the structure defined in the European Union Aviation Safety Agency Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Commission Implementing Regulation (EU) 2019/947: Annex I to ED Decision 2019/021/R. The guidance texts from the annex have been added for convenience, they are highlighted in grey.

13.1 UAS description

The UAS consists of a UAV and a GCS. The UAV is a hexacopter UAS, powered by two lithium-ion batteries. A companion computer is mounted, which intercepts all communication between the UAV Flight Controller (FC) and the GCS. This way, the companion computer has the high-level responsibility of controlling the UAV, while the FC has the low-level control, such as maintaining attitude, altitude and following route plans. The communication is transmitted through a UHF direct Command & Control (C2) link. The UAV is shown on the images below:

The GCS is operated by the Supervisor either indoors or from a GCS vehicle with an adequate work place. The GCS consists of a laptop dedicated for GCS use only, which runs the GCS software. It is plugged into an external power source to ensure continuous power throughout the mission. The UHF C2 link radio is connected to the GCS laptop. The C2 link radio antenna is mounted on a telescoping mast, capable of extending the antenna 10 meters into the air, in order to provide a long-range signal. Images of the GCS can be seen below:

GCS vehicle currently used for operations

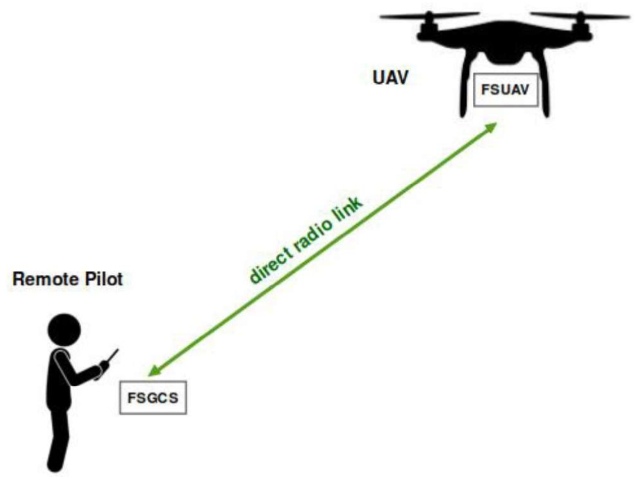
Supervisor operations desk

A Failsafe System (FS) is installed, which operates independent of the Unmanned Aerial Vehicle (UAV). The FS contains an UAV positioning system, a Flight Termination System (FTS) which shuts down the UAV motors, and a Parachute Recovery System (PRS). Specifically, the purpose of the FS is to:

- Provide the person in command of the UAV with an estimation of the UAV position and altitude independent of the information available from the UAV via the Ground Control Station (GCS), thereby enabling verification that the UAV estimated position and altitude are acceptable.

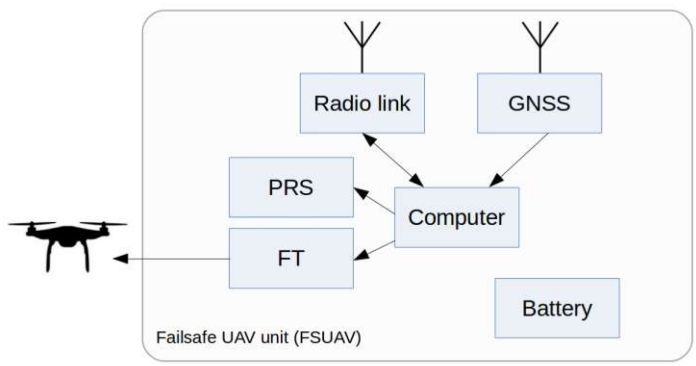
- Provide the person in command of the UAV with an independent means of manually performing a flight termination (FT) and parachute recovery.

- Detect if the UAV exits its flight envelope and performs an out-of-control descent. If so, automatically perform a FT and execute a parachute recovery.

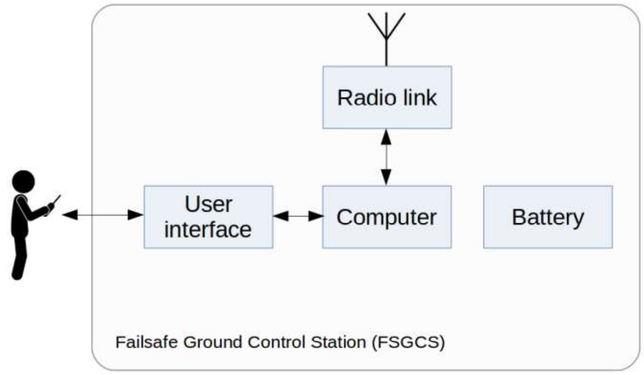


The Failsafe System Ground Control System (FSGCS) communicates with the Failsafe UAV unit (FSUAV) via a direct radio link

The FS consists of a unit installed on the UAV (FSUAV) and a Ground Control Station (FSGCS) located next to both the Pilots and the Supervisor as depicted in the below image. The link between the FSUAV and FSGCS is based on a direct radio link. Below are diagrams of the FSUAV and FSGCS units.



The FSUAV consists of a computer that via a radio link is in communication with the FSGCS. The computer relays independent information about position and altitude above MSL from the GNSS to the FSGCS. Upon request from the FSGCS a Flight Termination (FT) is activated followed by activation of the Parachute Recovery System (PRS). An independent battery powers the FSUAV. Only the FT subsystem (motor cut-off) is interfacing to the UAV.



The FSUAV consists of a computer that via a radio link is in communication with the FSGCS. The user interface presents Information from the FSUAV GNSS to the person in command of the UAS to activate the Flight Termination (FT). An independent battery powers the FSGCS.

The FS is further documented in the external appendix: Failsafe System Description and Specifications.

13.1.1 Unmanned aircraft (UA) segment

13.1.1.1 Airframe

This section should include the following:

(a) A detailed description of the physical characteristics of the UA (mass, centre-of-mass, dimensions, etc.), including photos, diagrams and schematics, if appropriate to support the description of the UA.

(1) Dimensions: for fixed-wing UA, the wingspan, fuselage length, body diameter etc.; for a rotorcraft, the length, width and height, propeller diameter, etc.;

(2) Mass: all the relevant masses such as the empty mass, MTOM, etc.; and

(3) Centre of gravity: the centre of gravity and limits if necessary.

(b) Materials: the main materials used and where they are used in the UA, highlighting in particular any new materials (new metal alloys or composites) or combinations of materials (composites 'tailored' to designs).

(c) Load limits: the capability of the airframe structure to withstand expected flight load limits.

(d) Sub-systems: any sub-systems such as a hydraulic system, environmental control system, parachute, brakes, etc.

The airframe is described in the table below.

1.1.1 Airframe	
Physical characteristics of the UA	
Aircraft type:	Multirotor.

(a-1) Wingspan (fixed-wing):	Not applicable.
(a-1) Fuselage length (fixed-wing):	Not applicable.
(a-1) Body diameter (fixed-wing):	Not applicable.
(a-1) Propeller diameter(s) (fixed-wing):	Not applicable.
(a-1) Length (multirotor):	≤ 80 cm.
(a-1) Width (multirotor):	≤ 80 cm.
(a-1) Height (multirotor):	≤ 80 cm.
(a-1) Propeller diameter (multirotor):	≤ 12 inches.
(a-2) Empty mass:	≤ 3.5 kg.
(a-2) Maximum Take-Off Mass (MTOM):	4.9 kg[27].
(a-3) Centre-Of-Mass (COM) placement:	Placed roughly at the geometric center of the UAV.
Materials of the UA	
(b) Main body material(s):	Carbon fiber tubes.
(b) Propeller material(s):	Plastic.
(b) Other materials:	Printed Circuit Board (PCB) frame and plastic fasteners.
Load limits	
(c) Load limits: the capability of the airframe structure to withstand expected flight load limits:	The motor-propeller combination delivers a maximum thrust of approximately 8 kg. The defined MTOM of 4.9 kg has been tested to leave a sufficient range of power for maneuvering the UAV within its flight envelope at maximum mean wind conditions.
Sub-systems	
(d) Sub-systems (hydraulic system, environmental control system, parachute, brakes, etc.):	The UAV is equipped with a Failsafe System (FS) with a parachute, which is described in 13.8.

13.1.1.2 UA performance characteristics

This section should include the following:
(a) the performance of the UA within the proposed flight envelope, specifically addressing at least the following items:

[27] Limited by the lift capacity of the used parachute.

(1)Performance: the

(i) maximum altitude;

(ii) maximum endurance;

(iii) maximum range;

(iv) maximum rate of climb;

(v) maximum rate of descent;

(vi) maximum bank angle; and

(vii) turn rate limits.

(2) Airspeeds: the

(i) slowest speed attainable;

(ii) stall speed (if applicable);

(iii) nominal cruise speed;

(iv) max cruise speed; and

(v) never-exceed airspeed.

(b) Any performance limitations due to environmental and meteorological conditions, specifically addressing the following items:

(1) wind speed limitations (headwind, crosswind, gusts);

(2) turbulence restrictions;

(3) rain, hail, snow, ash resistance or sensitivities;

(4) the minimum visibility conditions, if applicable;

(5) outside air temperature (OAT) limits; and

(6) in-flight icing:

(i) whether the proposed operating environment includes operations in icing Conditions;

(ii) whether the system has an icing detection capability, and if so, what indications, if any, the system provides to the remote pilot, and/or how the system responds; and

(iii) any icing protection capability of the UA, including any test data that demonstrates the performance of the icing protection system.

The UAV performance is described in the table below.

1.1.2 UA performance characteristics	
Performance of the UA	
(a-1-i) Maximum altitude:	120 m AGL.
(a-1-ii) Maximum endurance:	15 minutes.
(a-1-iii) Maximum range:	6 km

(a-1-iv) Maximum rate of climb:	4 m/s (defined in software).
(a-1-v) Maximum rate of descent:	3 m/s (defined in software).
(a-1-vi) Maximum bank angle:	45 degrees (defined in software).
(a-1-vii) Turn rate limits:	200 deg/s (defined in software).
Airspeeds	
(a-2-i) Slowest attainable speed:	0 m/s (hover).
(a-2-ii) Stall speed (if applicable):	Not applicable.
(a-2-iii) Nominal cruise speed:	The UAV cruises at 10 m/s ground speed (independent of airspeed) as defined in the operation.
(a-2-iv) Max cruise speed:	The UAV is software limited to a max cruise speed of 10 m/s ground speed.
(a-2-v) Never-exceed airspeed:	26 m/s based on max cruise speed and max gusts. This refers to the software limitation of the UAV.
Environmental and meteorological conditions	
(b-1) Maximum headwind, crosswind and gusts:	8 m/s head- and crosswind and 16 m/s gusts (all defined based on experience from flight tests).
(b-2) Turbulence restrictions:	Adhere to the above limits.
(b-3) Precipitation:	None (the UAV is not protected from water ingress).
(b-4) Minimum visibility:	5 kilometers (based on experience from flight tests, the air is too humid if the visibility is lower).
(b-5) Outside Air Temperature (OAT) limits:	4 degrees (to ensure zero risk of icing) to 40 degrees.
(b-6-i) Proposed operating environment includes operations in icing conditions:	No operation in icing conditions and no detection capability.
(b-6-ii) Icing detection capability, and if so, what indications, if any, the system provides to the remote pilot, and/or how the system responds:	
(b-6-iii) Icing protection capability of the UA, including any test data that demonstrates the performance of the icing protection system:	

13.1.1.3 Propulsion system

This section should include the following:

(a) Principle: A description of the propulsion system and its ability to provide reliable and sufficient power to take off, climb, and maintain flight at the expected mission altitudes.
(b) Fuel-powered propulsion systems

(1) The type (manufacturer organisation and model) of engine that is used;
(2) How many engines are installed;
(3) The type and the capacity of fuel that is used;
(4) How the engine performance is monitored;
(5) The status indicators, alerts (such as warning, caution and advisory), messages that are provided to the remote pilot;
(6) A description of the most critical propulsion-related failure modes/conditions and their impact on the operation of the system;
(7) How the UA responds, and the safeguards that are in place to mitigate the risk of a loss of engine power for each of the following:

(i) fuel starvation;
(ii) fuel contamination;
(iii) failed signal input from the remote pilot station (RPS); and
(iv) engine controller failure;

(8) The in-flight restart capabilities of the engine, if applicable, and if so, a description of the manual and/or automatic features of this capability;
(9) The fuel system and how it allows for adequate control of the fuel delivery to the engine, and provides for aircrew determination of the fuel remaining. This includes a system level diagram showing the location of the system in the UA and the fuel flow path; and
(10) How the fuel system is designed in terms of safety (fire detection and extinguishing, reduction of risk in case of impact, leak prevention, etc.).

(c) Electric-powered propulsion systems

(1) A high-level description of the electrical distribution architecture, including items such as regulators, switches, buses, and converters, as necessary;
(2) The type of motor that is used;
(3) The number of motors that are installed;
(4) The maximum continuous power output of the motor in watts;
(5) The maximum peak power output of the motor in watts;
(6) The current range of the motor in amps;
(7) Whether the propulsion system has a separate electrical source, and if not, how the power is managed with respect to the other systems of the UA;
(8) A description of the electrical system and how it distributes adequate power to meet the requirements of the receiving systems. This should include a system level diagram showing the electrical power distribution throughout the UA;
(9) How power is generated on board the UA (for example, generators, alternators, batteries).
(10) If a limited life power source such as batteries is used, the useful life of the

power source during normal and emergency conditions, and how this was Determined;

(11) How information on the battery status and the remaining battery capacity is provided to the remote pilot or the watchdog system;

(12) If available, a description of the source(s) of backup power for use in the event of a loss of the primary power source. This should include:

(i) the systems that are powered during backup power operation;

(ii) a description of any automatic or manual load shedding; and

(iii) how much operational time the backup power source provides, including the assumptions used to make this determination;

(13) How the performance of the propulsion system is monitored;

(14) The status indicators and alert (such as warning, caution and advisory) messages that are provided to the remote pilot;

(15) A description of the most critical propulsion-related failure modes/conditions and their impact on system operation;

(16) How the UA responds, and the safeguards that are in place to mitigate the risk of a propulsion system loss for each of the following:

(i) Low battery charge;

(ii) A failed signal input from the RPS; and

(iii) A motor controller failure;

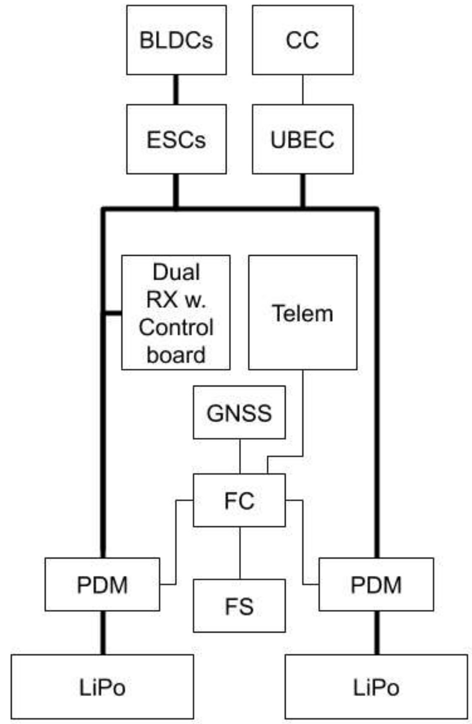
(17) If the motor has in-flight reset capabilities, a description of the manual and/or automatic features of this capability.

(d) Other propulsion systems: A description of these systems to a level of detail equivalent to the fuel and electrical propulsions sections above.

The UAV propulsion is described in the table below.

1.1.3 Propulsion system	
(a) Description of propulsion system and its ability to provide reliable and sufficient power to take off, climb, and maintain flight at the expected mission altitudes:	The propulsion system consists of six BrushLess Direct Current (BLDC) motors with 40 Ampere Electronic Speed Controllers (ESCs) and 12” plastic propellers. They are powered by two Lithium Polymer (LiPo) batteries. In total, this yields an 8 kg maximum thrust, which is 161.25% of the MTOM, leaving ample power for maneuvering, as tested in the UAS Type Test SOP.
(b/c) Propulsion type:	Electrical.
(c-1) High-level description of the electrical distribution architecture, including items such as regulators, switches, buses, and converters, as necessary:	The battery power is distributed through the system by an internal circuit in the UAV center body plate. Regulators feed the low voltage elements such as the flight controller and Companion Computer (CC). A

	detailed description is found in c-8, along with a diagram of the power distribution.
(c-2) Motor type:	BLDC.
(c-3) Number of motors:	6.
(c-4) Maximum continuous power output of motor in watts:	280 Watt pr. motor.
(c-5) Maximum peak power output of motor in watts:	Unknown.
(c-6) Current range of motor in amps:	0.6 - 16 Ampere.
(c-7) Separate electrical source or power management:	No separate electrical source. Two PDMs, one for each battery, distribute power to the motor controllers and the remaining avionics such as flight controller, GNSS, etc.
(c-8) Description of electrical system and how it distributes adequate power to meet the requirements of the receiving systems. This should include a system level diagram showing the electrical power distribution throughout the UA:	The two LiPo batteries supply 14.8V (nominal value). The unaltered power is distributed to the ESCs, while being regulated down to 5V for the flight controller. This regulation takes place in two Power Distribution Modules (PDMs), one for each battery. The PDMs are equipped with shunts, which protect against electric shorts in the batteries. If one battery short circuits, the shunt in the connected PDM will burn and eliminate the electrical connection to that battery, allowing the UAV to continue on the other battery alone. The flight controller powers its own peripherals, such as GNSS and telemetry. A Universal Battery Eliminator Circuit (UBEC) regulates the battery voltage down to 5V for the CC, as the 5V plugs for the PDMs are designed to only fit the Pixhawk's power port. The diagram below shows the mission-critical elements of the power distribution:

	 *BLDCs: motors, ESCs: electronic speed controllers, CC: companion computer, UBEC: voltage regulator, PDM: power distribution module, LiPo: lithium polymer battery, FC: flight controller, RX: radio control board and two RX receivers, GNSS: global navigation satellite system, Telem: telemetry, FS: failsafe system.* *The thin lines signify 5V, while the bold signifies full battery voltage.*
(c-9) Power generation (generators, alternators, batteries):	Two LiPo batteries.
(c-10) Useful life of power source during normal and emergency conditions, and how this was determined:	Depending on weather conditions approximately 11-14 minutes before the battery level reaches 33-34%. This has been determined by analysing flight records where the UAV has conducted BVLOS flights at height 100 m and speed 10 m/s of 5 km distance (this is approx. 25% longer than the planned flight for this Operation).
(c-11) How the battery status information and the remaining battery capacity is provided to the remote pilot or the watchdog system:	The remaining battery capacity (%) is presented to the Supervisor via the CGS.
(c-12) Backup power source(s) (if available), including which systems are powered, automatic and manual load shedding, operational time of backup power source:	See c-7 Separate electrical source above.
(c-13) Propulsion performance monitoring:	Ground speed and altitude are available to the Supervisor via the GCS screen.

(c-14) Status indicators and alerts for remote pilot/supervisor:	The remaining battery capacity (%) is presented to the Supervisor via the CGS.
(c-15) Description of most critical propulsion failure modes/conditions and their system operation impact:	Battery failure, motor failure, Electronic Speed Controller (ESC) failure, UAV will exit flight envelope. Another type of failure is flight controller failure, interfering with navigation, for instance by navigating towards coordinates 0,0 or similar.
(c-16-i) UA low battery safeguards and response:	At critically low battery the UAV will perform an emergency landing on site.
(c-16-ii) UA safeguards and response when RPS signal fail detected:	The UAV does not change behaviour during a GCS link failure. It will continue its current flight. The Supervisor will be alerted via the GCS and will have the ability to monitor the UAV position and altitude as well as perform a FT via the FSGCS. The response to a GCS link failure is defined as a contingency procedure for the Supervisor. In case both the UAV and the FSUAV simultaneously experience a link failure, the UAV is instructed to continue its mission which is considered the safest response given the operation defined in the ConOps.
(c-16-iii) UA motor controller failure safeguards and response:	See section 13.1.1.4 (c, d).
(c-17) In-flight reset capabilities:	If the link between the FSGCS and FSUAV is lost, both the FSUAV and FSGCS will periodically reset the communication hardware in an attempt to re-establish the link.
Other propulsion systems	
(d) A description of these systems to a level of detail equivalent to the fuel and electrical propulsions sections above:	Not applicable.

13.1.1.4 Flight control surfaces and actuators

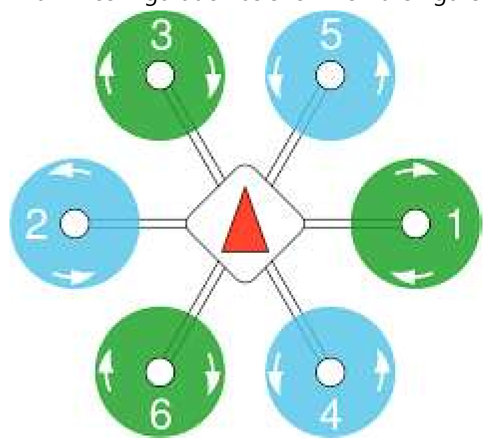
This section should include the following:

(a) A description of the design and operation of the flight control surfaces and servos/actuators, including a diagram showing the location of the control surfaces and the servos/actuators;

(b) A description of any potential failure modes and the corresponding mitigations;

(c) How the system responds to a servo/actuator failure; and

(d) How the remote-pilot or watchdog system is alerted of a servo/actuator malfunction.

<table>
<tr><th colspan="2">1.1.4 Flight control surfaces and actuators</th></tr>
<tr><td>(a) Description of design and operation of flight control surfaces and servos/actuators. Include a diagram showing the location of control surfaces and servos/actuators:</td><td>As the UAV is a multirotor, it possesses no control surfaces. It is a hexacopter with six actuators (motors) in an X-configuration as shown on the figure below.


Source:
https://dev.px4.io/v1.9.0/en/airframes/airframe_reference.html</td></tr>
<tr><td>(b) Description of potential failure modes and corresponding mitigations:</td><td rowspan="2">In case of an actuator failure, the UAV will most likely not generate sufficient lift to remain airborne and will thus start falling. In this event, the FS will detect that the drone exits its flight envelope and perform a flight termination, thereby stopping any functional actuators and ejecting the parachute.</td></tr>
<tr><td>(c) System response to a servo/actuator failure:</td></tr>
<tr><td>(d) How is the remote pilot or watchdog system alerted of a servo/actuator malfunction:</td><td>The flight termination will be relayed to the FSGCS, which will inform the Supervisor that the flight has been terminated.</td></tr>
</table>

13.1.1.5 Sensors

This section should describe the non-payload sensor equipment on board the UA and its role.

The UAVs flight controller is equipped with three accelerometers, gyroscopes and magnetometers, and two barometers, in order to provide sensor redundancy to the flight controller. Apart from these, a Here2 GNSS module is used for global positioning. Finally, the power distribution modules are equipped with current sensors for battery consumption measurements.

The FSUAV adds an independent GNSS module which provides the UAV position and altitude to the Supervisor via the FSGCS.

The FSUAV contains independent accelerometer- and barometer sensors used to detect if the UAV exits its flight envelope.

13.1.1.6 Payloads

This section should describe the payload equipment on board the UA, including all the payload configurations that significantly change the weight and balance, electrical loads, or flight dynamics.

The UAV is capable of carrying light payloads such as replica blood samples etc. depending on the purpose of the given flight.

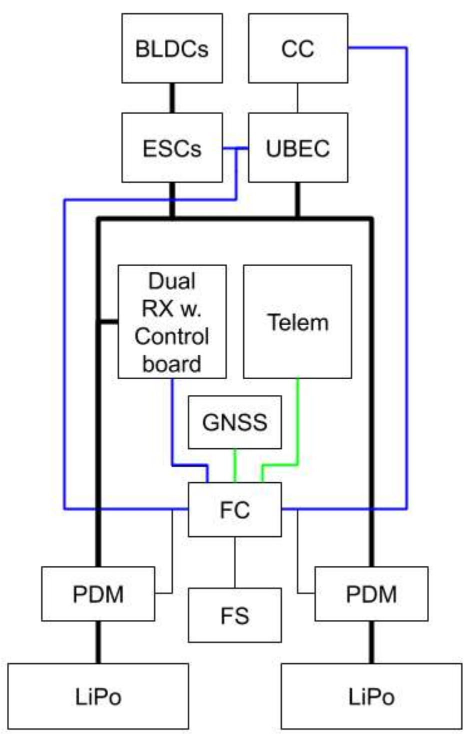
13.2 UAS control segment

This section should include the following:

13.2.1 General

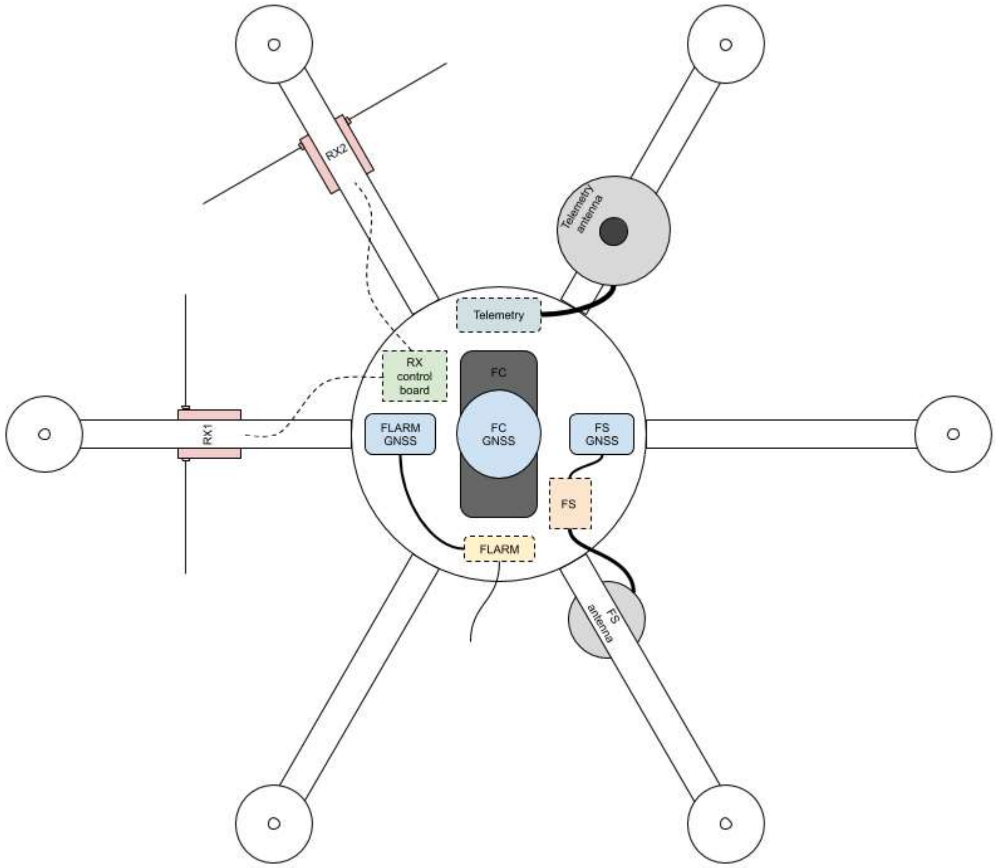
An overall system architecture diagram of the avionics architecture, including the location of all air data sensors, antennas, radios, and navigation equipment. A description of any redundant systems, if available.

An overall system architecture diagram, showing all mission-critical components can be seen below.



Black lines are power, green is data and power, and blue is purely data.

A diagram displaying the location of all air data sensors, antennas, radios, and navigation equipment is shown below.



The figure shows a sketch of the UA as seen from the top including approximate location of modules. The dashed lines indicate modules that are not placed on top of the UA, but further down in the layers. The C2 link antenna is pointing upwards, the FS antenna is pointing downwards.

13.2.2 Navigation

(a) How the UAS determines its location;
(b) How the UAS navigates to its intended destination;
(c) How the remote pilot responds to instructions from:
- (1) air traffic control;
- (2) UA observers or VOs (if applicable); and
- (3) other crew members (if applicable);

(d) The procedures to test the altimeter navigation system (position, altitude);
(e) How the system identifies and responds to a loss of the primary means of navigation;
(f) A description of any backup means of navigation; and
(g) How the system responds to a loss of the secondary means of navigation, if available.

2.2 Navigation	
(a) How does the UAS determine its location:	The UAV is equipped with a GNSS module for absolute navigation.
(b) How does the UAS navigate to its intended destination:	The UAV follows a predetermined or dynamic path plan in order to reach its destination, which is controlled by the Pixhawk 2.1 flight controller.
(c-1) Remote pilot response to instructions from air traffic control:	In VLOS, the Pilot has the possibility of fully taking over the UAV and manually fly it. In BVLOS, the Supervisor can change the height of the flight plan before starting the flight. When the UAS is executing the flightplan, the Supervisor can perform the following commands: Stop and loiter at current position. Return To Land. Land at current position. Continue mission from current position. Set-Height of the current loiter, and/or the current mission.
(c-2) Remote pilot response to instructions from UA observers or VOs (if applicable):	
(c-3) Remote pilot response to instructions from other crew members (if applicable):	
(d) Procedures to test the navigation system (position, altitude):	As part of the pre-flight check described in OD13 - Pre-flight Procedure, the position of the UAV shown on the GCS and the FSGCS is verified.
(e) How does the system identify and respond to a loss of the primary means of navigation:	The UAV will enter altitude hold, maintaining the current altitude. If GNSS is regained, the UAV will enter position hold. In both situations, the current mode will be maintained until otherwise instructed via the GCS or Flight Termination is executed via the FSGCS.
(f) Description of any backup means of navigation:	No backup means of navigation.
(g) System response to loss of secondary means of navigation, if available:	Not applicable.

13.2.3 Autopilot

(a) How the autopilot system was developed, and the industry or regulatory standards that were used in the development process.
(b) If the autopilot is a commercial off-the-shelf (COTS) product, the type/design and the production organisation, with the criteria that were used in selecting the COTS autopilot.

(c) The procedures used to install the autopilot and how its correct installation is verified, with references to any documents or procedures provided by the manufacturer's organisation and/or developed by the UAS operator's organisation.
(d) If the autopilot employs input limit parameters to keep the aircraft within defined limits (structural, performance, flight envelope, etc.), a list of those limits and a description of how these limits were defined and validated.
(e) The type of testing and validation that was performed (software-in-the-loop (SITL) and hardware-in-the-loop (HITL) simulations).

2.3 Autopilot	
(a) How was the flight controller system developed and were any industry or regulatory standards used in the process:	PX4 development is under governance by https://www.dronecode.org/. It is a community developed flight stack, reviewed, with almost 400 contributors and reviewers.
(b) If a COTS flight controller is used, describe type, production organisation and criteria used in selecting it:	A Pixhawk 2.1 flight controller, running a stable PX4[28] firmware release, has been chosen. It has been chosen, in part because the firmware is open-source. This transparency ensures data-privacy and complete control of firmware updates, which is not obtainable from a "black box" system such as DJI. In addition, the PX4 firmware is widely used, has 381 contributors and has been forked more than 9,700 times at the time of writing[29]. This means that by staying one or two stable releases behind the newest release, we are sure to use well-tested firmware. Finally, SDU has extensive prior knowledge using this flight-controller/firmware combination.
(c) Description of procedures used to install the autopilot and how its correct installation is verified, with references to any documents or procedures provided by the manufacturer's organisation and/or developed by the UAS operator's organisation:	Guidance for flight controller installation and subsequent testing is documented in the SOPs 'UAS Production SOP' and 'UAS Production Test SOP'.
(d) If the flight controller employs input limit parameters to keep the aircraft within defined limits (structural, performance, flight envelope, etc.), a list of those limits and a description of how these limits were defined and validated:	Each UAS has been tested according to the Type test SOP (available in the External appendix) which specifies configuration parameter readout as well as manual flight tests where the UAV is exposed to extreme inputs.

[28] https://px4.io/
[29] https://github.com/PX4/Firmware.

(e) The type of testing and validation that was performed (software-in-the-loop (SITL) and hardware-in-the-loop (HITL) simulations):	Each UAS has been tested according to the Type test SOP and Production test SOP (available in the External appendix). Subsequently the UAS has performed at least 10 BVLOS operations at HCA Airport[30] before being used in this operation. The principal mechanics and power components are currently undergoing extensive endurance tests where the UAV performs continuous flight at an indoor test facility for many hours (using an external power supply and optical tracking of the UAV for positioning)

13.2.3.1 Installation procedures

Installation is performed following the UAS Pixhawk 2.1 Installation SOP created by the manufacturer. Each new UAV flight controller is then tuned and uploaded with a set of parameters which, for instance, limits avionics parameters in order to keep the UAV within its flight envelope. This is done by following the UAS Parametrization and Tuning SOP developed by the operator.

13.2.4 Flight control system

(a) How the control surfaces (if any) respond to commands from the flight control computer/autopilot.
(b) A description of the flight modes (i.e. manual, artificial-stability, automatic, autonomous).
(c) Flight control computer/autopilot:

> (1) If there are any auxiliary controls, how the flight control computer interfaces with the auxiliary controls, and how they are protected against unintended activation.
> (2) A description of the flight control computer interfaces required to determine the flight status and to issue appropriate commands.
> (3) The operating system on which the flight controls are based.

The TX is capable of putting the flight controller in three different modes; manual, stabilized and position. However, none of these modes are used during a normal operation. The companion computer will upload a mission plan to the flight controller and then put it in mission mode in order to carry out the plan. When operating in VLOS, the Pilot will monitor the UAVs behaviour. If any issue occurs, the Pilot has the ability via the TX to override the mission by putting the flight controller in one of the three above mentioned modes and control the UAV manually.

2.4 Flight control system

[30] BVLOS permission: Journal TS30503-06794, 19. december 2019.

(a) Control surfaces' (if any) response to commands from the flight controller:	As the UA is a multirotor, no control surfaces are present.
(b) A description of the flight modes (i.e. manual, artificial-stability, automatic, autonomous):	The system supports four flight modes, three of which can be set from the TXs[31]: Manual: Mode where centered TX sticks level vehicle attitude (roll and pitch), with no maintenance of altitude and global position. Altitude: Mode where centered TX sticks level attitude vehicle and maintains altitude based on altimeter. The vehicle's global position is not maintained, and can drift due to wind. Position: Mode where centered TX sticks levels vehicle attitude and altitude and maintains global position based on GNSS. Mission: UA executes a predefined mission/flight plan that has been uploaded to the flight controller. The UA is put into this mode by the companion computer, by order from the GCS. During normal operation, only the 'Mission' mode is used. The three other modes are solely intended for contingencies during VLOS operation, in which the local Pilot will put the UAV in one of the other three modes, in order to manually regain control of the UAV and perform a controlled emergency landing. When doing so, the Pilot will prioritize the modes with the most assisting features, resulting in the following order to try: 'Position', 'Altitude', 'Manual'.
(c-1) Are there any auxiliary controls, if so, how they interface with the flight controller, and how they are protected from unintended activation:	No auxiliary controls are present. The flight controller controls only the ESCs for the BLDCs.
(c-2) A description of the flight controller interfaces required to determine the flight status and to issue appropriate commands:	The flight controller requires an external GNSS module for positioning and tracking, and a telemetry radio for receiving commands from the GCS and sending updates in return.
(c-3) Flight controller operating system:	PX4[32].

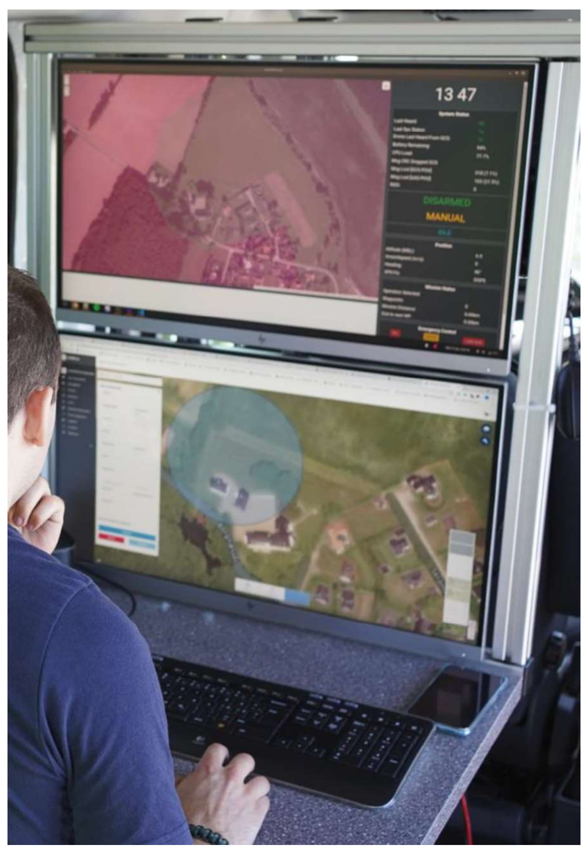
13.2.5 Remote pilot station (RPS)

(a) A description or a diagram of the RPS configuration, including screen captures of the control station displays.

[31] https://docs.px4.io/v1.9.0/en/flight_modes/.

[32] https://px4.io/

(b) How accurately the remote pilot can determine the attitude, altitude (or height) and position of the UA.
(c) The accuracy of the transmission of critical parameters to other airspace users/air traffic control (ATC).
(d) The critical commands that are safeguarded from inadvertent activation and how that is achieved (for example, is there a two-step process to command ‘switch the engine off’). The kinds of inadvertent input that the remote pilot could enter to cause an undesirable outcome (for example, accidentally hitting the ‘kill engine’ control in flight).
(e) Any other programmes that run concurrently on the ground control computer, and if there are any, the precautionary measures that are used to ensure that flight-critical processing will not be adversely affected.
(f) The provisions that are made against an RPS display or interface lock-up.
(g) The alerts (such as warning, caution and advisory) that the system provides to the remote pilot (e.g. low fuel or battery level, failure of critical systems, or operation out of control).
(h) A description of the means to provide power to the RPS, and redundancies, if any.

2.5 Remote pilot station (RPS)	
(a) Description or diagram of RPS configuration, including screen captures of displays:	The GCS consists of a dedicated laptop running Ubuntu Linux with the SDU developed GCS software based on Robot Operating System (ROS). 

	The image shows the to Supervisor views: The top is the GCS view of the operation while the bottom is the UTM view of the operation.
(b) Accuracy of RPS attitude, altitude and position:	Accuracy of position and altitude of the UAV (and thus the accuracy of the RPS information) is based on a GNSS receiver in Standard Positioning Services (SPS) mode. The theoretical absolute accuracy of SPS is <+/- 15 m in more than 95% of the time. The corresponding absolute accuracy of the altitude is correspondingly < +/- 22m more than 95% of the time. The practical realized accuracy is typically within 5-10 meter. Attitude information at the RPS is not considered relevant for BVLOS operation of a multirotor.
(c) Accuracy of transmission of critical parameters to other airspace users/ATC:	The accuracy of the tracking information (position and altitude) is identical to the above description.
(d) Critical commands safeguarded from inadvertent activation and how it is achieved and the inadvertent input that the remote pilot could enter to cause an undesirable outcome:	Flight Termination is conducted via the FS using an emergency stop button of the type used for industrial installations.
(e) Other programs running concurrently on the ground control computer, if so, what precautionary measures are used to ensure that flight-critical processing will not be adversely affected:	The laptop used is a dedicated GCS computer and does not run other programs (with a graphical user interface) concurrently.
(f) Provisions made against an RPS display or interface lock-up:	The GCS laptop has been configured to not enter power-save mode of any kind. If the GCS laptop by error performs a lock up, the FSGCS provides vital information about the flight while the Operator attempts to restore normal operation. The operational procedures for this are detailed in OD62 - Subsystem Failure SOP.
(g) Alerts (such as warning, caution and advisory) that the system provides to the remote pilot:	The user interface is based on a single main view where vital information is shown as highlighted (colored) texts.
(h) Description of the means to power the RPS and redundancies, if any.	The GCS laptop is connected to an external power source and thus uses its internal battery as Uninterruptible Power Source (UPS).

13.2.6 Detect and avoid (DAA) system

(a) Aircraft conflict avoidance

(1) A description of the system/equipment that is installed for collaborative conflict avoidance (e.g. SSR, TCAS, ADS-B, FLARM, etc.).
(2) If the equipment is qualified, details of the detailed qualification to the respective standard.
(3) If the equipment is not qualified, the criteria that were used in selecting the System.
(b) Non-collaborative conflict avoidance:
A description of the equipment that is installed (e.g. vision-based, PSR data, LIDAR, etc.).
(c) Obstacle conflict avoidance
A description of the system/equipment that is installed, if any, for obstacle collision avoidance.
(d) Avoidance of adverse weather conditions
A description of the system/equipment that is installed, if any, for the avoidance of adverse weather conditions.
(e) Standard
(1) If the equipment is qualified, a list of the detailed qualification to the respective standard.
(2) If the equipment is not qualified, the criteria that were used in selecting the System.
(f) A description of any interface between the conflict avoidance system and the flight control computer.
(g) A description of the principles that govern the installed DAA system
(h) A description of the role of the remote pilot or any other remote crew in the DAA system.
(i) A description of the known limitations of the DAA system.

2.6 Detect and avoid (DAA) system	
Aircraft conflict avoidance	
(a-1) A description of the system/equipment that is installed for collaborative conflict avoidance (e.g. SSR, TCAS, ADS-B, FLARM, etc.):	The UAV is equipped with FLARM in/out and ADS-B in. While the FLARM out is active and may warn other nearby airspace users, the FLARM and ADS-B are installed for research purposes only and are thus not considered air risk mitigation factors in this risk assessment.
(a-2) If the equipment is qualified, details of the detailed qualification to the respective standard:	The FLARM is developed to the standards described below: - CEPT/ERC Recommendation 70-03 - Decision 2006/771/CE: Harmonization of the radio spectrum for use by SRD, limiting use of the SRD band h1.4 at 868.0 - 868.6 MHz to a transmission duty cycle of 1%/time and the output power to 25 mW ERP - Directive 2014/53/EC: Radio Equipment Directive (RED) - ETSI EN 300 220: Electromagnetic compatibility and Radio spectrum Matters (ERM)

	- ETSI EN 301 489: Electromagnetic Compatibility (EMC) for radio equipment and services
(a-3) If the equipment is not qualified, the criteria that were used in selecting the System:	A comparison of FLARM modules has been made. The PowerFLARM UAV was chosen due to being lightweight and due to its compatibility with the Pixhawk communication protocol MAVLink, which makes it possible to incorporate FLARM-based sense and avoid at a later stage.
Non-collaborative conflict avoidance	
(b) A description of the equipment that is installed (e.g. vision-based, PSR data, LIDAR, etc.):	No such equipment installed.
Obstacle conflict avoidance	
(c) A description of the system/equipment that is installed, if any, for obstacle collision avoidance:	No such equipment installed.
Avoidance of adverse weather conditions	
(d) A description of the system/equipment that is installed, if any, for the avoidance of adverse weather conditions:	No such equipment installed. Adverse weather conditions are avoided by operational procedures defined in: OD10 - Pre-operation Procedure OD13 - Pre-flight Procedure OD11 - Weather Procedure OD63 - Poor Weather Conditions
Standard	
(e-1) If the equipment is qualified, a list of the detailed qualification to the respective standard:	Not applicable.
(e-2) If the equipment is not qualified, the criteria that were used in selecting the System:	Not applicable.
Descriptions	
(f) A description of any interface between the conflict avoidance system and the flight control computer:	Not applicable.
(g) A description of the principles that govern the installed DAA system:	Not applicable.
(h) A description of the role of the remote pilot or any other remote crew in the DAA system:	See 1.0.2.5.4 for information on the role of remote crew in the DAA.

(i) A description of the known limitations of the DAA system:	See 1.0.2.5.4 for description of remote crew DAA.

13.3 Containment system

(a) A description of the principles of the system/equipment used to perform containment functions for:

(1) avoidance of specific area(s) or volume(s); or

(2) confinement in a given area or volume.

(b) The system information and, if applicable, supporting evidence that demonstrates the reliability of the containment system.

3 Containment system	
(a-1) Description of the principles of the system/equipment used to perform containment functions for avoidance of specific area(s) or volume(s):	The UAS and the FS described in *13.1 UAS description* provides independent information to the Supervisor about the UAV position and altitude. The Supervisor monitors the flight and performs a contingency procedure if the UAV exits its flight geometry. The GCS allows control of the UAV and in case this is not functional, the independent FS allows flight termination and parachute recovery.
(a-2) Description of the principles of the system/equipment used to perform containment functions for confinement in a given area or volume:	
(b) The system information and, if applicable, supporting evidence that demonstrates the reliability of the containment system:	

13.4 Ground support equipment (GSE) segment

(a) A description of all the support equipment that is used on the ground, such as launch or recovery systems, generators, and power supplies.

(b) A description of the standard equipment available, and the backup or emergency equipment.

(c) A description of how the UAS is transported on the ground.

4 Ground support equipment (GSE) segment	
(a) A description of all the support equipment that is used on the ground, such as launch or recovery systems, generators, and power supplies:	No support equipment used.
(b) A description of the standard equipment available, and the backup or emergency equipment:	Not applicable.

(c) A description of how the UAS is transported on the ground:	The UAS is transported in a vehicle, safely fastened and with UAV propellers removed, in order to avoid damage during transport.

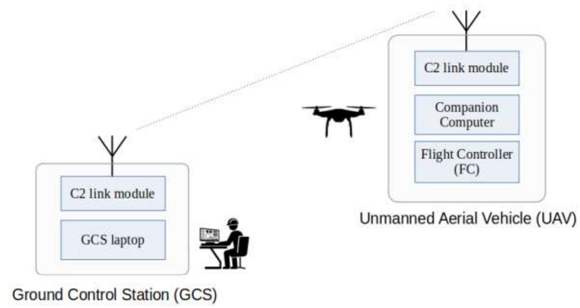
13.5 Command and control (C2) link segment

(a) The standard(s) with which the system is compliant.
(b) A detailed diagram that shows the system architecture of the C2 link, including informational or data flows and the performance of the subsystem, and values for the data rates and latencies, if known.
(c) A description of the control link(s) connecting the UA to the RPS and any other ground systems or infrastructures, if applicable, specifically addressing the following items:

(1) The spectrum that will be used for the control link and how the use of this spectrum has been coordinated. If approval of the spectrum is not required, the regulation that was used to authorise the frequency.
(2) The type of signal processing and/or link security (i.e. encryption) that is Employed.
(3) The data link margin in terms of the overall link bandwidth at the maximum anticipated distance from the RPS, and how it was determined.
(4) If there is a radio signal strength and/or health indicator or similar display to the remote pilot, how the signal strength and health values were determined, and the threshold values that represent a critically degraded signal.
(5) If the system employs redundant and/or independent control links, how different the design is, and the likely common failure modes.
(6) For satellite links, an estimate of the latencies associated with using the satellite link for aircraft control and for air traffic control communications.
(7) The design characteristics that prevent or mitigate the loss of the data link due to the following:

(i) RF or other interference;
(ii) flight beyond the communications range;
(iii) antenna masking (during turns and/or at high attitude angles);
(iv) a loss of functionality of the RPS;
(v) a loss of functionality of the UA; and
(vi) atmospheric attenuation, including precipitation.

5 Command and control (C2) link segment
Standards

(a) The standard(s) with which the system is compliant:	No known standards for UAV C2 links. Based on a permission from Energistyrelsen (ref. External appendix) the C2 link is operated in compliance with the rules and regulation for radio amateur communication[33]. This means that there are no requirements for CE- or other certification of the C2 link.
Diagram	
(b) A detailed diagram that shows the system architecture of the C2 link, including informational or data flows and the performance of the subsystem, and values for the data rates and latencies, if known:	 The C2 link is based on a direct data link between the GCS and the UAV. The latency over air is thus negligible unless the packet loss becomes significant. All vital data such as position, altitude, remaining battery capacity and system state are transmitted at 1 Hz or faster.
Control link(s) connecting the UA to the RPS and any other ground systems or infrastructures	
(c) A description of the control link(s) connecting the UA to the RPS and any other ground systems or infrastructures, if applicable:	The C2 links is based on DMD DL1 Radio modules[34].
(c-1) The spectrum that will be used for the control link and how the use of this spectrum has been coordinated. If approval of the spectrum is not required, the regulation that was used to authorise the frequency:	The C2 link uses the 432-438 MHz spectrum. Based on a permission from Energistyrelsen (ref. External appendix) the C2 link is operated in compliance with the rules and regulation for radio amateur communication[35]. This means that approval of the frequency spectrum is not required.
(c-2) The type of signal processing and/or link security (i.e. encryption) that is employed:	Due to the operation in compliance with the rules and regulation for radio amateur communication, encryption of the radio link is not permitted.

[33] https://www.retsinformation.dk/eli/lta/2018/1335
[34] https://www.tienda.dmd.es/epages/ea0697.sf/en_GB/?ObjectPath=/Shops/ea0697/Products/KITXLRSDL1V1/SubProducts/KITXLRSDL1V1-89.
[35] https://www.retsinformation.dk/eli/lta/2018/1335

	The radio link uses the Mavlink Protocol 1.0 which includes a CRC16 check for all packets.
(c-3) The data link margin in terms of the overall link bandwidth at the maximum anticipated distance from the RPS, and how it was determined:	The C2 link has been tested at the range of 3.7 km which is close to the maximum distance from the GCS to the farthest extent of the operational volume and risk buffers. At this range the C2 link loses less than 10% of the data packets while operating at a height of approx. 40 m AGL. This is considered adequate, especially because the FS has been successfully tested to 7.5 km range when operating 50 m AGL.
(c-4) If there is a radio signal strength and/or health indicator or similar display to the remote pilot, how the signal strength and health values were determined, and the threshold values that represent a critically degraded signal:	The GCS shows how many seconds it has been since it last heard from the UAV. It shows both for the mission-computer and the PX4 and how long since the mission-computer heard from the GCS. The numbers are color-coded so less than 5s is green, between 5s and 10s is yellow and over 10s is red. The thresholds were chosen as normal communication would always receive data within 5s. Periodic interference could put it just above, but if more than 10s has gone, the connection is deemed lost or rapidly degrading.
(c-5) If the system employs redundant and/or independent control links, how different the design is, and the likely common failure modes:	In addition to the described C2 link, the Pilot may control the UAV via a TX link while within VLOS. This is based on a 2.4 GHz Spektrum[36] RC transmitter (CE certified) with a range of at least 500 m. Via the TX, the Pilot is able to switch to manual flight and perform a safe landing.
(c-6) For satellite links, an estimate of the latencies associated with using the satellite link for aircraft control and for air traffic control communications:	Not applicable.
(c-7-i) The design characteristics that prevent or mitigate the loss of the data link due to RF or other interference:	The C2 link antenna has been mounted on top of the UAV, separated as far as possible from RF-noisy components. In addition, the UAS Production SOP instructs in shielding the battery eliminator circuit with copper foil tape.
(c-7-ii) The design characteristics that prevent or mitigate the loss of the data link due to flight beyond the communications range:	The C2 link has been tested successfully at the range of 3.7 km which is > 90% of the maximum distance from the GCS to the farthest extent of the operational volume and risk buffers. In addition the FS has been successfully tested to 7.5 km range when operating the UAV at 50 m AGL.

[36] http://www.spektrumrc.com/

(c-7-iii) The design characteristics that prevent or mitigate the loss of the data link due to antenna masking (during turns and/or at high attitude angles):	The antenna has been mounted on top of the UAV, while the GCS antenna is mounted on a mast at 10 m AGL. The UAV operates at 100 m height, and due to the wind limitation of 8 m/s, the angle of the UAV will not shield the antenna. As the antenna points upwards, it is possible to experience some antenna shading if the UAV is right above the GCS antenna.
(c-7-iv) The design characteristics that prevent or mitigate the loss of the data link due to a loss of functionality of the RPS:	In case of a loss of functionality of the GCS, the FS provides a fully redundant link to the UAV providing information on position and altitude to the Supervisor, and enabling activation of the flight termination.
(c-7-v) The design characteristics that prevent or mitigate the loss of the data link due to a loss of functionality of the UA:	In case of a loss of functionality of the UAV, the FS provides a fully redundant link to the UAV providing information on position and altitude to the Supervisor, and enabling activation of the flight termination.
(c-7-vi) The design characteristics that prevent or mitigate the loss of the data link due to atmospheric attenuation, including precipitation:	Not applicable as operations are executed in no rain and minimum 5 km visibility.

13.6 C2 link degradation

A description of the system functions in case of a C2 link degradation:
(a) Whether the C2 link degradation status is available and in what form (e.g. degraded, critical, automatic messages).
(b) How the status of the C2 link degradation is announced to the remote pilot (e.g. visual, haptic, or sound). A description of the associated contingency procedures.
(c) Other.

6 C2 link degradation	
(a) Whether the C2 link degradation status is available and in what form (e.g. degraded, critical, automatic messages):	The degradation is visible by a counter that shows how many seconds has elapsed since the last message went through. If the seconds since "last-heard" increments more than usual, then it is link degradation. The Supervisor can then judge when the link is slightly, critically, or completely degraded.
(b) How the status of the C2 link degradation is announced to the remote pilot (e.g. visual, haptic, or sound). A description of the associated contingency procedures:	The C2 link status is color-coded on the GCS, such that green, yellow, and red signify; good link status, some degradation, and critical degradation respectively.

(c) Other:	None.

13.7 C2 link loss

(a) The conditions that could lead to a loss of the C2 link.
(b) The measures in case of a loss of the C2 link.
(c) A description of the clear and distinct aural and visual alerts to the remote pilot for any case of a lost link.
(d) A description of the established lost link strategy presented in the UAS operating manual, taking into account the emergency recovery capability.
(e) A description of how the geo-awareness or geo-fencing system is used in this case, if available.
(f) The lost link strategy, and, if incorporated, the re-acquisition process in order to try to reestablish the link in a reasonably short time.

7 C2 link loss	
(a) Conditions that could lead to a loss of the C2 link:	Radio failure, Antenna Failure, Distance too far, interference, loss of radio-LOS, loss of power to either radio-module.
(b) Measures in case of a loss of the C2 link:	OD61 - Radio Link Failure SOP OD91 - Complete link failure SOP
(c) Describe the clear and distinct aural and visual alerts to the remote pilot for any case of a lost link:	Visual counter on the GCS which shows how many seconds since the last time a message was received from the UAV. It turns red when it has been more than 10s since last heard from the UAV.
(d) Describe the established lost link strategy presented in the UAS operating manual, taking into account the emergency recovery capability:	Not applicable, see (f).
(e) Describe how the geo-awareness or geo-fencing system is used in this case, if available:	The FS has an independent GNSS receiver and can, when connected to a computer, show the position on a map together with the flight boundaries. If the UAV is seen to break the geo-fence and cannot be called back or landed as normal via the GCSI, the FS flight termination can be activated.

(f) Describe the lost link strategy, and, if incorporated, the re-acquisition process in order to try to reestablish the link in a reasonably short time:	The lost link strategy is defined in the OD61 - Radio Link Failure contingency SOP. If reestablishing normal operation is not feasible and the Supervisor loses control of the operation, the OD91 - Complete Link Failure emergency SOP is activated.

13.8 Safety features

(a) A description of the single failure modes and their recovery mode(s), if any.
(b) A description of the emergency recovery capability to prevent risks to third-parties. This typically consists of:

> (1) a flight termination system (FTS), procedure or function that aims to immediately end the flight; or
> (2) an automatic recovery system (ARS) that is implemented through UAS crew command or by the on board systems. This may include an automatic pre-programmed course of action to reach a predefined and unpopulated forced landing area; or
> (3) any combination of the above, or other methods.

(c) The applicant should provide both a functional and physical diagram of the global UA system with a clear depiction of its constituent components, and, where applicable, an indication of its peculiar features (e.g. independent power supplies, redundancies, etc.)

8 Safety features	
(a) Describe the single failure modes and their recovery mode(s), if any:	GNSS failure (UAV GNSS not reporting valid data) - This failure mode is detected by the FC which transitions into recovery mode: Switches to Altitude mode if height estimation is available, otherwise stabilized mode. It will stay in loiter forever until otherwise told. If a critical low battery failure occurs during loiter, this failure will take priority and the UAV will perform an emergency landing on site (ref c-16-i). GNSS failure (FS GNSS not reporting valid data) - This failure mode is detected by the FS which reports this to the Supervisor via the FSGCS. No recovery mode is activated automatically. UAV failure (Navigation failure such as an unexpected route or height, a fly-away or flight geometry exit)

	- This failure mode may be caused by GNSS spoofing or failure, by a flight controller failure or by a route planning failure. This failure mode is not (necessarily) detected by the UAS itself. With the exception of GNSS spoofing which may also affect the FS GNSS, the FS will present independent information about the UAV position and altitude to the pilot. UAV failure (Critical low battery) - This failure mode is detected by the flight controller which then transitions into recovery mode: At critical low battery the UAV will perform an emergency landing on site (ref c-16-i). UAV failure (exit flight envelope) - This failure mode is detected by the FS: The FS monitors if the UAV exits its flight envelope. If failure mode occurs, FT is activated. See (b-1) for detailed info. C2 link failure - This failure mode is detected by the FC and by the GCS: See 13.7 C2 link loss for detailed info. FS link failure - This failure mode is detected by the FS. During link failure both the FSUAV and FSGCS will periodically reset the communication hardware in an attempt to re-establish the link.
(b-1) Describe the flight termination system (FTS) emergency recovery capability to prevent risks to third-parties:	The FS containing an independent FTS is described in section *13.1 UAS description* and further in the External appendix: Failsafe System Description and Specifications
(b-2) Describe the automatic recovery system (ARS) emergency recovery capability, implemented through UAS crew command or by the on board systems, to prevent risks to third-parties:	
(b-3) Any combination of the above, or other methods:	
(c) Provide both a functional and physical diagram of the global UA system with a clear depiction of its constituent components, and, where applicable, an indication of its peculiar features (e.g. independent power supplies, redundancies, etc.):	Please see section *13.1 UAS description*.