**Project ID** : Fly-Radar
**Project Title** : *Low-frequency multi-mode (SAR and penetrating) radar on-board light-weight UAV for Earth and Planetary exploration*
**Call** : H2020-MSCA-RISE-2020

## WP4 - Design and manufacturing UAV

# D4.1 - Advanced UAV Design

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|---|---|
| **Due date** | 30th November 2021 |
| **Delivery date** | 22th November 2021 |
| **Deliverable type** | R |
| **Dissemination level** | PU |

### Document History

| Version | Date | Description |
|---|---|---|
| v0.0.0 | 02/09/2021 | Draft |
| v1.0.0 | 12/09/2021 | Revision since meeting with CO.RI.S.T.A. |
| v1.0.1 | 17/12/2021 | Minor spell and syntax fixes |

# Contents




This project has received funding from the European Union's Horizon 2020 research and innovation program under MSCA-RISE 2020 grant agreement No 101007973.

# 1 Publishable Summary

This report presents the collaborative work done between CO.RI.S.T.A. and HYPERION SEVEN to come up with a design for the drone that will be used for the FlyRadar project. This report concludes first that the optimal design to be used is a classical quadcopter, and one suitable for the anticipated payload weight would be the TUNDRA, built by HEXADRONE. Various mechanical pieces will have to be built in order to mount the radar and its various antennas onto the drone. Finally, it was first foreseen that the use of a tether between the drone and a ground station could be utilized in order to power the drone indefinitely and have a fiber optic line to the ground, which would allow to retrieve the captured data in real time and avoid to need of an on-board computer. However, the radar design of CO.RI.S.T.A. includes a computer small enough that an optical link is no longer needed. Moreover, in the aim of having the drone fly in the desert (terrestrial terrains analogous to Mars), it is probably better to stick to the traditional way of powering a drone, i.e. a battery, making the need for a tether inexistent.

# 2 Introduction

The Work Package 4 aims to come up with a drone capable of carrying the radar proposed by CO.RI.S.T.A. on the Work Package 3. However, the proposal of CO.RI.S.T.A. is not definitive yet. As a consequence, this report is committed to be changed as CO.RI.S.T.A. updates its proposal.

This report will first expose the constrains and specifications of the drone. Then we will review the general aspect of our drone, to conclude that a commercial drone can be utilized, with some modifications to it. Indeed, we need it to carry the FlyRadar's payload and withstand the high temperature that can experienced in the test environment.

# 3 Specifications

This section will expose the specifications of the drone, its flight environment and the preliminary specifications of the radar that leads to the drone's specifications.

## 3.1 Flight Environment

According the the deliverable 1.1, the surface of Mars is mostly made of a porous dry material, e.g. regolith. Analogous environment will be find on earth in the Sahara desert. This environment can reach temperatures up to 50°C during the day and the design of the drone will require cooling solution to endure this extreme heat.

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## 3.2 Radar Specification

The project basic idea is to come up with a radar both capable of being a SAR and a GPR. Such requirements implies to use SDR (Software Defined Radio), where hardware components are replaced by software components. Usually FPGAs will be in charge of generating the radio signal and receiving it. The deliverable 1.1 suggests to have a sounding capability of around or over 100m.

Let's also note that the more powerful electric drones can carry a payload of around 20kg. Nonetheless, these drones are really big, and when it comes to more standards drones (less tnan 2 meters of span), this payload is brought down to 5kg.

### 3.2.1 Radar Components

A radar using the SDR technology is divided into four main parts:

- **The antenna(s)**: Obviously, a radar needs an antenna to emit and receive radio signals. The *monostatic radars* uses only one antenna which periodically switches between emitting and receiving mode. The *bistatic radar* uses two distinct antennas (one dedicated to emission, the other to reception)
- **The SDR system**: This system is the part that will handle the signal generation and reception. It contains the programmable FPGA which will contain the code that will be defining the system's operating modes.
- **The antenna(s) front-end**: The signal generated by the SDR system has to be amplified to be emitted by the antenna and routed to the proper antenna. All this is done by the front end.
- **The data management system**: The SDR system will output data based on the radar measurements. This data must be processed and stored. This piece of equipment will likely be a traditional computer.

### 3.2.2 Foreseen Tradeoff Between Airborne and Grounded

Because of this weight limit, it appears that it is not feasible to have a fully airborne radar. Thus it was initially planned to separate the radar into two pieces: the airborne section and the grounded section. The airborne section would be made of the antennas, the SDR system and the antennas front end. The data management system would be left to the ground segment. However, given the radar choice made by CO.RI.S.T.A., such link is no longer needed (see section 4.2.2).

### 3.2.3 Radar Proposal (WP3)

Given the previous specifications, CO.RI.S.T.A has proposed that SDR system will be composed of components sold by ETTUS, a radar component company.

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More precisely, their choice landed on the USRP E320, a board integrating two Tx and Rx ports.

For SAR sounding, the design of the radar will be bistatic, as CO.RI.S.T.A. plans to use one antenna for horizontal polarization and one for vertical polarization, utilizing Yagi-Uda antennas. However, for GPR sounding, the radar will be monostatic, utilizing a folded bipolar antenna.

## 3.3 Airborne Weight

Based on the preliminary choice of airborne components, one can set as an upper limit for the weight of the payload to 3 kilograms. Let's not forget that the fiber optic deployed from the drone will cause an additional charge to it. We will then set our payload's max weight to 4 kg.

# 4 Preliminary Proposals

## 4.1 The Drone Itself

### 4.1.1 Global Design

First of, we need to define the type of drone that we need to come up with. The two main drone classes are the following:

- **Fixed Wings**: These drones are equipped with an actual wing, that need a forward speed to get lift. They are really energy efficient and benefit from a large max mass to empty mass (i.e. mass without any payload and batteries) ratio. Thus they can carry large payload compared to their weight. However, when a large payload is needed, the required size for this kind of drone can be fairly large. In addition to that, these drones can't achieve hover in most cases.

- **Rotary Wings**: Theses drones are equipped with rotating blades. They are hover capable, and more volume efficient than a fixed wing drone. However, they are far from being as power efficient than their fixed counterpart and suffer from a lower max mass to empty mass ratio.

Because of the minimum speed required by the fixed wings drones, it appears that rotary wings drones are better choice for our maneuverability needs. Moreover, even if this former category of drone is less capable of carrying weight, it is though easily doable to carry a 4kg payload. In the following of this report, the term drone will then refer to rotary wings drones.

Many choices of such drones are still available:

- **Helicopter shaped**: Being one of the first designs of the rotary wings drones, the helicopter shaped drone is capable of carrying large weights. However, its large rotor needs to be powered by an high torque motor, hence the need of a gas motor. This means that the main rotor has a

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large momentum that can easily do harm if badly employed. Moreover, the stirring of these machines is done through the use of a *swash plate*, a friction mechanism that induce a varying angle of attack to the blade throughout its rotation. This piece of equipment is known to be a large source of failure of these drones.

- **Counter-rotating single rotor**: Similar to the ingenuity rover, the counter-rotating single rotor drone is the tail-rotor-less alternative of the helicopter shaped drones. The use of counter rotating rotor makes it more energy efficient but the use of a single rotor force the need of large blades, thus large momentum and large operating hazard. This design still uses a swash plate.

- **Tricopter**: The multicopter with the least amount of rotors, the tricopter has two front rotors and a back rotor. The back rotor is usually tilted with a servomotor to have control over the yaw axis. This drone have a poor maneuverability compared to the other rotary wings drones because of the odd number of motors, that induce a dissymmetry between each motors.

- **Quadri/Hexa/Octocopter**: The most classical drones, with an even number of motors, half of them running in one direction, the other half in the other direction. Thought not being naturally stable (in opposition to helicopter shaped drones, that are naturally stable if equipped with a bell bar), the active stabilization algorithm are really efficient nowadays and stability is no longer a concern. One has to choose between using four, six or eight motors when it comes to designing one and the choice is based on the following criterion. More rotors means more sharing of the load, thus more max payload mass. But more motors means less space to fit all the propellers, which means smaller propellers. And smaller propellers usually turns at higher rotational speeds, which means more noise and less efficiency. Thus an octocopter can carry more weight than a quadricopter, but it is more noisy and less power efficient.

This previous list tries to shed light on the fact that drones with an odd number of rotors are unsuited mostly because they are less maneuverable or less reliable. Even if the project initially leaned towards an octocopter (according to the projects objectives), quadcopters are completely capable of carrying 4kg and allow to have more space under the drone that are not directly under the propeller air flow. For example, it is important (but not critical) to minimize the airflow on the antenna in order to minimize their vibration and thus the stress on the mechanical components.

This very last point is also the reason why an X-shaped drone is more pertinent than an +-shaped drone. A +-shaped drone has a motor on its front, one on its back, one on its left and one on its right. But the radar, because of it being a SAR, need to be side mounted, then on the left or the right, just under the propellers. That's why an X configuration is more suited to the objective of limiting the airflow on the antennas.

*Conclusion: An X-shaped quadricopter should be used*

### 4.1.2 Materials

When it comes to choose a material to build a UAV that is lightweight and strong, there is rarely a better choice than carbon fiber. Though not being machinable, the carbon fiber comes in two standards shapes that are the only one needed to build a drone: flat sheet for the center plate where the electronic will be mounted and tube for the arms. If machined pieces are needed, aluminum can be used if it is a structural component, otherwise 3d printed pieces can be made. Please note that some 3D printing filament, like PLA, can start to deform at 60°C. Special attention has to be given to the choice of the filament if using 3d printing.

### 4.1.3 Single or Doubled Motors

Each arms of the quadricopter can be built classically with a single motor on it end. However, it is possible to use a second motor installed upside down rotating in the opposite direction. It create a counter-rotating rotor that is known to be more power efficient than a single motor. Thus each motor is redundant and a motor failure don't lead to a catastrophic failure of the drone (which would be the case if the motors were not doubled). The reverse side of the coin is that it can lead to more noise, more vibrations, and a more complicated drone to build. Though doubled motors are a great choice and can be used in the production drone, we will not be using this technique on our demonstrator for simplicity reasons.

*Conclusion: Single motors will be used, but doubled motors can be a great choice in production*

### 4.1.4 Electrical Hardware

In order to achieve a basic stabilization of the drone, the motors (or more precisely the motor controllers) must be linked to a flight controller (FC). This type of controller is usually built on arduino-like controller (STM32 processors based). Depending on their clocking speed, number of input and number of cores, the controllers get a label. The more common ones are F1, F3, F4, F7 and H7. The F1 and F3 are low-end old flight controllers that can't manage to run up to date code. The F4 FC are a common appreciated board, featuring a clocking at 100 MHz and can handle a looptime at 8 kHz. The looptime is the clocking of the internal stabilization loop of the drone. The faster the loop, the sturdier the drone. However, F4 are slowly being superseded by F7 FC that are clocked at 217 MHz and can handle looptimes up to 32 kHz. Finally, H7 is the latest FC on date, clocked at 480 MHz. While it seems useful, existing firmware still don't actually need such performances. All in all, our drone must be equipped with a F4, F7 or H7 FC.

In order to achieve basic flight capabilities and stabilization, one must equip this drone with a basic 9 axis IMU (featuring gyroscope, accelerometer and magnetometer), and with a GPS to obtain more advance stabilization and navigation features from the FC: waypoint mission, return to home, non drifting

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hovers... One of the most known flight controller are the Omnibus FC, whose small size is appreciated by racing pilot. But the Omnibus FC (and equivalents) does not feature standardized ports but holes in the printed circuit board to directly solder components to it. For a more professional looking approach, the Pixhawk 4 board comes in handy, with a built-in 9 axis IMU, GPS support (even RTK support), flight telemetry, running on a F7 chip

*Conclusion: The Pixhawk 4 flight controller can be used with a GPS*

### 4.1.5 Communication

Even if we will keep a tethered linked to the drone with a optic fiber, we will still control the drone using radio signals. This choice is highly motivated by the stability of today's radio solutions and simplicity to implement it on a drone. As a matter of fact, the Pixhawk is built to be controlled with a standard radio receiver.

**Frequency Band** When it comes to choose a Frequency Band, four factors have to be discussed:

- Wether to choose a public band or not
- The type of range we expect from our drone
- The bandwidth we need
- The environment in which we are flying the drone (perturbations, already set up radio links...)

First of, it is highly advisable to set up a drone that utilizes the European public bands in order not to have to get a flight permission each time we flight. Then we can use a simple rule that states the higher the communication frequency, the larger the bandwidth, but the lower the range of the communication. Finally, the flight environment we are targeting are supposedly empty from radiofrequency perturbations. Two public frequency bands are good candidates for this purpose. The 868MHz band is capable of long range telecommunication (> 20 km) but will not allow to broadcast large packets of data (such as video, more than 1 Mb/s). The 2.4GHz band is not as long range capable (> 2km) but has a usefully large bandwidth (> 20Mb/s). Given that our drone will be tethered, long range is not a crucial need and we can choose 2.4 GHz band to privilege the bandwidth in case we need to broadcast video.

*Conclusion: 2.4GHz band can be utilized to profit from a large bandwith*

### 4.1.6 Drone Proposal

The previously listed features are already grouped together in an existing drone, the TUNDRA commercialized by Hexadrone. The TRUNDRA is an X-shaped quadricopter intended to be a modular drone, which allows it to adapt to the customer's request and the payload he wants to embark. It is capable of lifting a

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payload of more than 4kg (an 8kg payload has been tested successfully, however it is needed to fine tune the drone) with a flightime of 30 minutes. It utilizes a Pixhawk 4, with an Herelink radiosystem running in the 2.4GHz band, capable of streaming two HDMIs signals. It is built with plenty of useful interfaces to mount payloads.

### 4.1.7 Cooling

However, the TUNDRA is not made to fly in temperatures around 50°C. Indeed, most components are rated for temperatures from -20°C to 50°C but not above. Moreover, the components can heat up (in particular the flight controller, the electronic speed controllers and the voltage regulator) and can rise the temperature in the drone's fuselage way above 50°C. For these reasons, the fuselage must be cooled. The first cooling solution will be to put fans in the fuselage in order to maintain a steady airflow, that will keep the inside of the fuselage at ambient temperature. If this is not enough, we could install Peltier modules on the components that need to. However, this last solution can quickly be heavy and energy consuming.

## 4.2 Drone's Payload

### 4.2.1 Power Segment

There are two solutions to power the drone. We can either power the drone through a standard battery, or power it from the ground through a power cable. The latter solution would require a power segment on the drone. In fact, the drone needs so much power that we need to step up the voltage running through the cable between the ground and the drone for it not to melt due to Joule's loss. The power segment would step down the high voltage in the cable to a lower voltage usable by the drone.

This method can be quite heavy and difficult to operate in the environment where the drone is supposed to be tested, that is why for testing it will be preferable to use a standard battery. Such a battery (LiPo, 6 cells, 50 Ah) ensures a 30 minutes flight time for the TUNDRA loaded with 4kg, which is sufficient for our tests. Several batteries can be brought on the terrain to multiply the number of flights.

*Conclusion: The drone will not be powered from the ground, but directly from a battery*

### 4.2.2 Communication Segment

The very first design of this mission was to set up an optical link between the drone and the ground in order to transmit all the data acquired by the radar. However, the radar chosen by CO.RI.S.T.A. integrates its very own on-board computer with storage capabilities (through an micro SD card). In all the cases, the captured data can't reasonably be computed on the fly, the advantage of the optical link is not obvious. The speed and storage capabilities of the above mentioned on-board computer are yet to be tested and confronted to our need, but it is highly likely that we will be using the on-board storage instead of retrieving all the data in-flight. By this mean, we would eliminate every need for a tether and then free our drone from the distance constraint of the tether.

*Conclusion: It is highly likely that we will not use an optical link but store all the data on the on-board computer.*

### 4.2.3 Radar Segment

It remains to integrate the radar under the drone. As detailed before, the radar has three components: the USRP, the front-end and the antenna(s) (one if doing GRP sounding, two if doing SAR sounding).

The USRP and the front-end will be integrated under the belly of the drone by the use of a mechanical piece that will be developed once the radar is received.

Regarding the antennas, two mounts will be developed, one for each mission: GPR and SAR. For both mission the antennas will be placed as well under the belly of the drone. The GPR has a simple folded dipole that is place perpendicular to the movement of the drone. The SAR uses two antennas that looks towards the side of the drone, both separated by a minimum distance (of the order of magnitude of the wavelength of the radar's frequency).

## 4.3 Ground Segment

The previous section stated that a tethered link is highly improbable, and it is the same for the ground segment. However, if we finally conclude that it is still needed, here is what would be needed to set up.

### 4.3.1 Ground Hardware

The optic fiber deployed obviously has to be linked to a computer. It is however not clear how powerful this computer has to be, in terms of storage speed and CPU power. Ideally, this computer will be powered with a battery to keep the whole system as mobile as possible.

### 4.3.2 Theter Management

The original solution utilized by Hyperion Seven for its tethered drones is a winch that regulates the tension in the tether. This is useful when the tether is used for safety purposes and the drone needs to be quickly pulled back in case of failure. This system is heavy and need a high power supply. Instead we could use a passive winch that automatically retrieves the deployed tethered with a spring. This would put a tension that increases with the distance of the drone from the ground station, which is something that we don't want. An even simpler solution will be used. The tether will be pulled by the drone from its storage but will not be automatically retrieved.

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