Project ID: **Fly-Radar**

Project Title: **Low-frequency multi-mode (SAR and penetrating) radar onboard light-weight UAV for Earth and Planetary exploration**

Call: **H2020-MSCA-RISE-2020**

WP2: System Requirements

D2.2: Specification of Instrument Requirements & System requirement document for Planetary exploration and Earth Science including performance requirement

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0.Abstract

The technical requirements necessary to achieve the scientific requirements are discussed in this deliverable for the UAV, then for the radar and finally for the complete system. The most limiting parameters for the UAV are the weight and the available charge of the batteries. It is shown that on Earth the UAV with a payload of 4.5 kg will be able to fly for more than 30 minutes. On Mars, the energy for takeoff of a similar UAV are at least twice those on Earth. These conditions are impossible to reach. A solution of a UAV attached by a cable to a rover is proposed. The UAV will be powered trough the cable by the rover. The Radar will operate in the same way on Mars and on the Earth. It will be necessary to work on the aerodynamics of antennas in order they will not affect the stability of flight. Finally, in order to georeferenced the data, the terrestrial UAV will be equipped by a GNSS and IMU. The Martian UAV will be equipped by an IMU. Both systems will be equipped by a camera the images of which will be processed by photogrammetric techniques in order t derive Digital Elevation Models and ortho-images.

1.Introduction

The objective of this second deliverable (D2.1) is to set the performance and limits of the Fly Radar instrument in relation to the scientific objectives defined in D2.1. As a reminder, the main results of D2.1 are given in Table 1.

	Earth	Mars
Vertical Resolution [m]	0.1 to 5 m	0.1 to 5 m
Horizontal Resolution [m]	0.1	0.1
Covered surface [km^2]	1	0.5
Distance between tracks [m]	<10	<20

Table 1: Performance parameters expected from scientific requirements.

The Fly Radar instrument comprises two subsystems which are the UAV on the one hand, and the radar on the other. The performance of each instrument will define the final properties of the system. The properties of the drone will define the surface to be studied as well as the spacing between the flight lines. Radar properties will define the vertical and horizontal resolutions of the instrument. Finally, the energy availability, the UAV's carrying capacities, the Radar's miniaturization capacities will define part of the final performance of the system. The final performance will also be controlled by the positioning capabilities of the instrument as well as the recording capabilities of the radar signal associated with the positioning. These different parameters are easy to define for a system dedicated to the exploration of the Earth. The proposed values will be much more speculative for a device intended for the exploration of Mars.

2. UAV performances

2.1UAV on Earth

The performance of a UAV is limited by both technical and regulatory constraints. The payload carried by a drone represents up to 65% of the total charge of the device, batteries included. A drone weighing 10 kg in total will carry a load of approximately 6.5 kg including batteries. The capacity of the batteries depends on their weight. Currently, the weight of 30 Ah batteries is around 2.6 kg. Such a battery allows the drone to fly for about an hour when empty. The autonomy decreases with the payload (figure 1) to 30 minutes for a load of 4.5 kg excluding the battery. In this case, the battery is not used to power the payload.

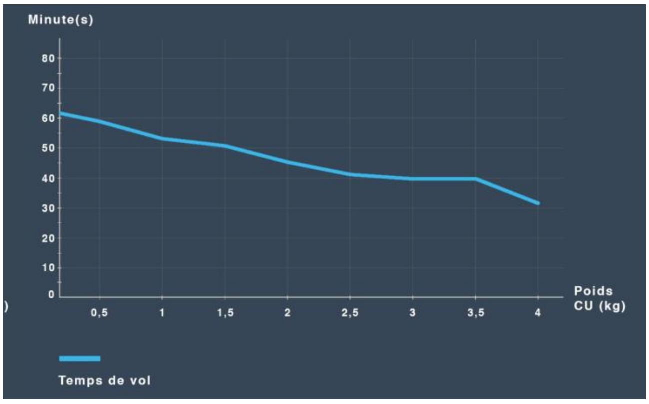

Figure 1: Relationship between payload weight and flight time for a drone weighing 10 kg. (https://tundra.hexadrone.fr/specifications).The payload is not powered by the drone battery.

It is therefore possible to fly for at least half an hour with a drone. The speed of flight has little effect on the autonomy of the device. If the drone is programmed to fly at 7 m.s-1 (25 km.h^{-1}), it will cover a distance of 25 km. An area of one km^2, flown over with an inter-track of 10 m can be flown over in at least 5 flights minimum taking a safety margin of 20%.

The second limit on performance is related to regulations. Currently each country has its own regulations and its own constraints. For Europe, general regulations should be applicable in 2023. The regulations provide for different flight scenarios depending on the location of the overflight with a limit on the altitude and the distance to the pilot specific to each scenario. Currently, in Europe, the flight ceiling is located 120 m above the ground and the aircraft must not go more than 1000 m from the pilot for flights in open areas without an audience, or 2 km with the presence of observers. It will be necessary to ensure flight rules for each country where the Fly Radar system will be used.

2.2 UAV sur Mars

The Martian atmosphere is thin and represents on average 0.6% of the Earth's atmosphere in terms of ground pressure (610 Pa on Mars for 101 325 Pa on Earth). Martian gravity is about a third of Earth's gravity (3.711 m / s^2 for 9.81 m / s^2 on Earth). The only drone that has flown on the surface of Mars is “Ingenuity” which is a technological demonstrator carrying a camera. Ingenuity weighs 1.8 kg including 0.3 kg of battery capable of delivering 350 W for 90 seconds. It is equipped with a double rotor operating blades 1.2 m in diameter (https://mars.nasa.gov/technology/helicopter/).

Rankine-Froude theory (e.g. Wilson and Lissaman, 1974) makes it possible to dimension in the first order the power required to support an aircraft powered by propellers. This theory relates the surface S of the disc swept by the rotor blades, the thrust F of the rotor, the speed v_i of the air through the rotor (called the induced speed). From the principle of conservation of momentum, we find for an aircraft in hovering flight:

$$F = 2\rho S v_i^2 \text{ with } \rho\text{, density of the atmosphere (Eq. 1)}$$

$$v_i = \sqrt{\frac{F}{2\rho S}} \text{ (Eq. 2)}$$

$$P = F v_i = \sqrt{\frac{F^3}{2\rho S}} \text{ (Eq. 3)}$$

Figure 2 gives the power required for hovering for an efficiency of 0.5 of the propulsion system. The theory indicates that for a UAV of 10 kg, it is necessary to develop a power of 2500 W. In climb flight, Rankine Froude's theory predicts a power 50% greater than that of hovering for a climb speed of 3 ms^{-1}. It will therefore be necessary to develop 3750 W for takeoff of the UAV at this rate of ascent.

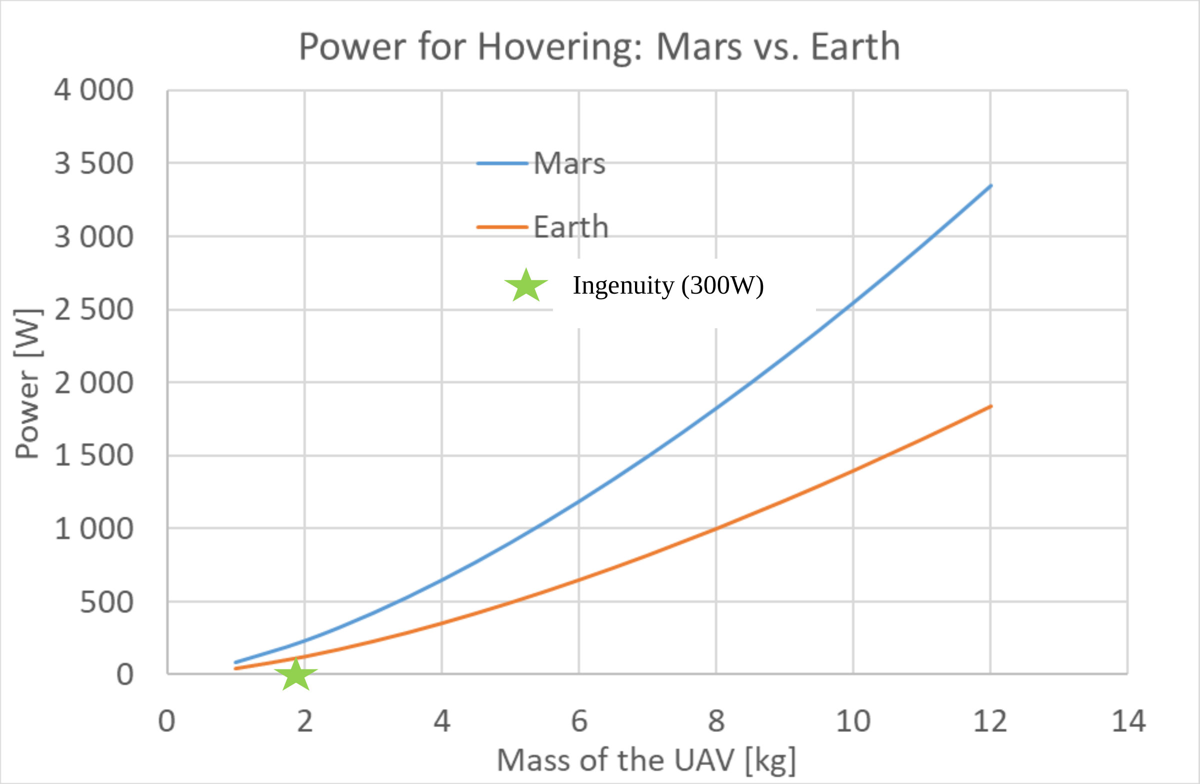

Figure 2: Power for hovering considering the theory of Rankin Froude and an efficiency of 0.5 in Martian (g=3.71 m.s^{-2}, ρ=0.020 kg.m^{-3}) and terrestrial (g=9.81 m.s^{-2}, ρ=1.225 kg.m^{-3}) conditions. The length of the blades is 0.5 m in both cases. The example of Ingenuity is reported (green star).

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The amount of electrical charge needed to maintain a 10 kg UAV on Mars for 1 second using 12V motors will be: I = 3750/12 = 312.5 A. A 30 Ah battery would therefore discharge in 345 s (30 * 3600 / 312.5) or 5 to 6 minutes for a complete discharge and rather 275 s for a discharge of 80% which would respect the rules of good practice. Flight time with such a battery would therefore be limited and would not achieve the desired goals. The simple preceding calculation does not take multirotors into account and therefore overestimates the flight time. These calculations also do not take into account the low Martian temperatures unfavorable to the use of batteries.

The solution lies either in lightening the UAV and Radar or in slaving the UAV to a base that will have to be mobile. The base can be used as a drone battery recharging station using the rover's internal source. Another solution would be to use a drone tethered to the rover whose link cable would allow the transport of energy and information. This last solution would not allow a large radius of action of the Fly Radar system around its base but would allow flight frequencies much higher than any other solution.

3. Radar performances

Parameters that drive the radars performances have been described I the Deliverable 1.1. They are mainly the frequency of emission that controls the resolution and the depth of investigation. More the frenquency is high, more the resolution is high and the depth of investigation is reduced.

Radar performances will not be different on Erath and on Mars. According to the geological context and the expectation of the mission, it will be necessary to adjust radar frequency.

The radar will be developed with the SDR technology and will consist in four main parts (see D1.1 for more information about each component):

- The antenna(s)
- The SDR
- The Power System
- The Data Management System

Specific antennas have to be designed and tested . The antenna should focus the signal and should receive the signal transmitted from ground. The best way to reconcile these two functions is to use two antennas, one specialized for emission and the other specialized for reception. Aerodynamic constraints will be included in the antenna design in order that they will not affect UAV stability in the wind. It is planned to install a 1.2 m long folded dipole antenna for GPR applications. Two conjugated YagiUda antennas will be installed for SAR applications in order to acquire a polarized signal. On antenna will transmit while the other will receive.

For the expected applications, the radar will be able to operate on a range of frequencies from 80 MHz to 2 GHz. The frequency will be selected according the properties of ground and the expected properties of the expected data. The resolution will range from 0.20 to 5 m with a depth of penetration ranging from 2 to 50 m according to ground composition. The SDR will drive the emission at the expected frequencies toward the antenna and will received the raw signal from the antenna before processing. SDR are now common and do not require particular attention.

The power system will operate at 12V on a specific battery on board of the UAV for the terrestrial solution. That will limit the power variation that could occur for the driving of the UAV. The power system will be localized in the rover for the Martian system.

Data will be stored on board of the UAV for the terrestrial solution on a dedicated minicomputer through a RJ45 plug. For the Martian solution, data will be transmitted to the rover through the cable that will rely the UAV to the rover.

The whole system is designed to weigh less than 4.5 kg.

4. System Performances

The Fly Radar system will produce radargrams which must be positioned as best as possible in a geographical or cartographic reference. This therefore requires the transport of a GNSS positioning system on Earth, and another on Mars capable of locating the UAV as well as the data generated.

On Earth, Fly Radar will carry a differential GNSS and an inertial unit (IMU) from which it will be possible to estimate the position and attitude of the UAV during the flight. It will also be necessary to calculate a Digital Terrain Model (DTM) and an orthoimage (plane image) at a resolution of 0.1 m. Radar data will be projected onto this DEM. It will therefore be necessary to embark an optical shooting system to perform these DEM calculations using photogrammetry techniques.

On Mars, it is not possible to use a satellite positioning system of an artificial object located on the surface of this planet. The positioning of the drone can be done by inverting the data of an inertial station. This positioning will be relative to a starting position or a particular point like the rover. As on Earth, it will be necessary to embark an optical shooting system to calculate DTMs and ortho-images on which the results will be projected. The data could also be produced by image indexing techniques (Mallet et al., 2000). Such positioning methods can produce data positioned to pixel precision. The elevation above ground of the UAV is a essential parameter used to compute precise DTM’s. This measure will be done by combining data from the radar (time of the first echo received by the radar from the surface) with a laser altimeter.

5. Conclusion

The Fly Radar UAV equipped with a radar that will operate on Earth will be able to fly for 30 minutes with a payload of 4.5 kg. The payload will constrict of a SDR, a power system dedicated to the radar, a data storage system and one or two antennas specially aerodynamically designed. On Mars, the atmosphere density necessitates for flying a power equal to twice the power necessary on Earth. The classical solution of a UAV with internal batteries is not viable. We propose thus that the UAV will be powered through a dedicated cable relying it to a rover.

Moreover, the Fly Radar system will be equipped by positioning system in order to georeferenced the data.

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The georeferencing will be done by a GNSS and IMU solution on Earth. The gereferencing will be less precise on Mars on which we propose to use a relative georeferencing from images taken by the UAV during its flights.

6 Bibliography

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