FlyRADAR

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

Call: H2020-MSCA-RISE-2020

WP5 – Model Qualification Campaign

D5.1: Qualification Plan

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List of Abbreviations

QP	Qualification Plan
SAR	Synthetic Aperture Radar
UAV	Unmanned Aerial Vehicle
WP	Work Package

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Publishable summary

The qualification of the instrument suite assures that the radar and drone and their integration will comply with the FlyRadar objectives, project standards and end-user requirements.

The activity of the WP includes:

- Identification of tests that will shall demonstrate, ahead of the field test campaigns (WP6), that the radar and drone, after integration, are operational and performing as planned. Tests may be carried out in the laboratory, numerically, or in the field;
- Design and implementation of the tests;
- Analysis of the test results;
- Checking that the results are in agreement with the scientific requirements.

This deliverable (5.1) covers the identification of the tests that shall be conducted.

It mainly consists of a table, provided in annex. The table is commented in the main body of the document. It is divided into 5 parts.

Part 1 defines the end-user parameters (mainly of scientific nature), evaluates the expected conformity of the current radar design (WP3) in sounding mode, describes the testbeds to be implemented to check this conformity, and provides the criterion for a satisfactory test result. Part 2 does the same except that the radar parameters to be tested are for the SAR mode. in Part 3, instead of the radar, the drone design (WP4) is checked against the end-user requirements. Part 4 is for the parameters that require consistency between end-user requirements, radar design, and drone design altogether. Part 5 is for the parameters that need some consistency between the radar and drone designs.

An update to this deliverable will be prepared after the mid-term meeting to be held at IRSPS on June 13th, 2022.

1. Introduction

The table and report are based on previous deliverables (D1.1, D1.2, D2.1, D2.2, D3.1, D4.1) as well as separate CO.RI.S.T.A. reports.

These sources of information were complemented by several online meetings between CBK PAN, CO.RI.S.T.A., Hyperion Seven, and IRSPS, during which the end-user, radar, and drone parameters were discussed in detail and adjusted.

The end-user, scientific requirements were transformed into quantitative parameters related to the geological contexts that characterize the field campaign anticipated sites, extended to the expected geologic conditions on Mars, since the system has been thought to be operative on both planets.

The qualification table (Annex) includes some text in red. This text contains provisional information that will be updated after the FlyRadar mid-term meeting held in Pescara on June

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13th, 2022. It will be released in the final version of the present deliverable (D5.1). In the table, columns that include "Y" and "N" indicate whether a parameter value checks positively (Yes) or negatively (No) against the required value, respectively.

The qualification process will be carried on by analysis of the documentation, indoor laboratory and numerical tests and if necessary, in an adequate outdoor environment. It will be reported in Deliverable D5.2.

2. Qualification table description

2.1. End-user requirements vs sounding mode

The scientific requirements for the sounding mode are: imaging, permittivity and required penetration depth

2.1.1. Subsurface structure imaging

The objective of the sounding mode is to obtain a vertical profile of the subsurface that depends on of the electromagnetic processes as measured by the instrument. The bandwidth is the range of frequencies considered. The central frequency is where the peak of the signal amplitude is located (Reynolds, 2011). For the radar, the frequency range is 30-300 MHz (VHF), equivalent the wavelength range 1-10 m, with a central frequency of 80 MHz and bandwidth of 10 MHz. These values are in agreement with the scientific requirements and in the table. The frequency values will be carefully checked in laboratory. The test will not request integration to the drone; therefore the laboratory tests of may take place before integration, i.e. between June and September 2022 (M17-M20).

2.1.2. Permittivity

We will consider the real permittivity (ε’), hereafter called "permittivity" for simplicity. Permittivity increases with the frequency (Reynolds, 2011). The range of permittivity for the considered range of frequencies and geological material, assumed to not contain liquid water; is ε’ =2-30 (Campbell and Ulrichs, 1969). Note that although the campaign sites were selected to not contain a water table, its presence (pure liquid water permittivity is 80) would still be detected by the instrument. The radiometric detectability, for the radar, is 1 db. The permittivity tests that will be done in laboratory requires radar and drone integration. Subsequently, a calibration in flight on a flat, simple surface, such as a clear lake surface, or a flat desert area, may need to be done.

2.1.3. Penetration depth

The penetration depth indicates the ability of the electromagnetic signal to propagate at depth (Campbell, 2002). The required penetration depth is 0-15 m. In this depth range, the geologic features which are anticipated to be detected in the campaign sites include, for instance:

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volcanic dykes, faults, and other stratigraphic interfaces. The expected radar penetration depth is 2-50 m, in conformity with the scientific requirements. The test, using the radar only, will consist in making theoretical models.

2.2. End-user requirements vs SAR capabilities

2.2.1. Surface imaging

The SAR mode is designed to obtain an image of the surface of the studied area. In SAR mode, the radar frequency range is 1-0.3 GHz (P-band), equivalent to a wavelength range of 0.3-1 m. Preliminary radar design has chosen a central frequency of 435 MHz with a bandwidth of 40 MHz. All these parameters are in conformity with the scientific requirement. The appropriate frequency tests are conducted during radar construction. Tests after integration to the drone are estimated to be unnecessary.

2.2.2. Mapping/polarization

Polarization accounts for propagation of the electric field in the medium, summing two signal components, H (Horizontal) and V (Vertical). Using different polarization modes (HH, VV, HV and/or VH) is useful to characterize and map the natural surfaces. Each of them may highlight different surface properties, such as surface roughness and humidity, that can reveal useful for geological interpretations. The four acquisition modes will be possible by the SAR design, complying with the scientific requirements. SAR mapping capability testing obviously requires radar and drone integration. The SAR modes are planned to be calibrated in a desert area.

Reflectivity

The reflectivity (ε0), which when measured in geological media is usually replaced by reflectance, is anticipated in the geological field to be in the range 0.1-0.95. The radar's reflectivity range of detection is at the moment not yet known. Matching the required range is not thought to be a major technical issue. The reflectivity range will be measured after radar and drone integration in the lab and using numerical models using various well-characterised surfaces.

2.3. End-user requirements vs UAV capabilities

2.3.1. Flight Autonomy

Drone autonomy is one of the most important parameters for planning geological surveying during the test campaigns. the important parameters, from the scientific point of view, include, the maximum surface area that can be covered in one fight, as well as the linear flight distance autonomy. A useful flight scenario would be that the drone flies following a grid that could for instance consist of lines *L* of length 1000 m, separated by a distance *D* of 10 m, and repeated 15 times. This corresponds to ~15 km of linear autonomy. The drone time autonomy, which

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depend on the flight conditions and the specifications of the on-board battery, is estimated to amount to a nominal 25 min, with nominal speed 10 m/s, and nominal flight distance autonomy of 15-17 km.

These values are adapted to the end-user requirements. They assume that the radar is not more than 3 kg, which is in the current targets of the radar design. Flight autonomy would decrease if the anticipated 3 kg of radar weight are exceeded. Drone flight autonomy tests can be performed with the radar; however they can also be done with an equivalent dead mass.

2.3.2. Atmospheric environment tolerance

The atmospheric environment parameters which are important to test include the maximum temperature and wind speed. The anticipated maximum temperature is 45°C. Maximum wind speed is estimated to be 11 km/h. The drone temperature tolerance is 50°C; and the maximum wind speed is estimated to 40 km/h. The environmental tests include a theoretical thermal test and a weighted (3kg) drone flight test. The temperature test does not require radar integration. The drone elements will be individually tested. The wind test needs either radar integration, or integration of a 3 kg dead mass test. The tests will pay particular attention to flight stability as a function of wind conditions.

2.4. End-user requirements vs radar and SAR capabilities

2.4.1. Spatial resolution in radar sounding mode

Spatial resolution is a major scientific requirements, dictated by the scale of geological objects to be identified and characterised. Spatial resolution includes the along-track and cross-track resolutions. The scientific needs are 20 m along-track and 200 m across-track. An additional constraint is provided by flight regulations pertaining to UAVs in the flight campaign countries. The selected flight altitude range of 50-150 m adheres to the regulations in force in Morocco, where for UAVs less than 25 kg, the regulation stipulates that the flight altitude should be at least 50 m over people, and not more than 150 m above the ground (the distance to the nearest airport needs also to be at least 8km).

The radar is being designed so as to obtain the desired along-track and cross-track resolutions, for a flight altitude above ground of 120 m. This altitude falls in the range of 50-300 m that the drone complies with.

The resolution tests will consist of theoretical models, instrument integration is therefore not necessary. Post-integration flights at the nominal flight altitude will make possible to confirm the models.

2.4.2. Spatial resolution in SAR mode

In SAR mode, the along-track and cross-track resolutions required by the end-user are both 5 m, with the same flight altitude constraints, imposed by country regulations. The resolution

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values anticipated by the radar design are 4.6-4.7 m and 3.8-6.9 m, respectively, for along-track and cross-track resolution. These values shall be obtained for a flight altitude above ground of 100 m. This altitude falls in the range of 50-300 m that the drone complies with.

Geolocation

Geolocation will be independently provided by two GPS devices, both on-board the radar and the drone. The dedicated GPS exploited by radar system will be used to support data processing on ground, as far as motion compensation is concerned, and to allow precise image geocoding and ground projection. Drone system will instead rely on its own GPS for navigation. Data from the two GPS systems on board are independent and no integration is foreseen.

Redundancy will be helpful to determine any geolocation anomaly in one of the two GPS signals received during flight by comparing the values obtained by the two systems.

2.5. Radar requirements vs UAV capabilities

2.5.1. Radar - drone connectivity

The drone needs to be electrically connected to the drone. The currently selected connection option between the radar and the drone is through a 4 Pinned XLR adapter (to be confirmed in the final version of this deliverable). On the drone side, the cable will be fixed to the drone through a XT60 connector. The successful connectivity will be checked during flights which may be targeted for other purposes; no distinct flight experiment is required.

2.5.2. Radar mounting scheme

The radar will be attached to the drone using two customised mechanical elements present on drone, as indicated in the Deliverable D4.1.

2.5.3. Radar weight

The total weight of the radar (including antenna) is expected to be 3 kg. The nominal behaviour of the drone as described in this report assumes a radar weight of 3 kg. However, a radar weight of 4 kg can be accommodated by the drone, at the expense of degradation of autonomy.

Aerodynamics

The radar system is asymmetrical due to constraints imposed by the SAR side antenna (see Deliverable D3.1). The drone itself is symmetrical and its centre of mass is at the centre of the drone. This may affect the aerodynamics of the radar-drone integrated system. However, due to the small mass (0.3 kg) of the side antenna (Deliverable D.3.1), the offset centre of mass of the radar is anticipated to have a minor impact on the flight aerodynamics, which will be checked with the post-integration flight parameters: flight time, speed, distance, and geolocation data.

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3. Conclusion

This report sets the frame for the qualification tests that should ensure successful field campaigns. The end-user requirements, mainly scientific, but also related to country regulations for light UAVs, will be checked against the radar and the drone, which are being constructed, according to the testbeds identified in this report.

Simultaneously, preparation of this report led to technical clarification of some aspects of the designs of the radar and the drone, which should lead to smooth instrument and vehicle integration.

The planned qualification tests will cover all the major aspects of the airborne radar prototype that are critical to the scientific success of the FlyRadar field campaigns in WP6. The qualification table in the annex synthesises the tested parameters and indicates the testing protocols. A loose timing for the test is proposed, it will be refined at the FlyRadar mid-term meeting.

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5. Annex: Qualification Table

Qualification Table: Conformity between radar design, drone design, and end-user requirements, and description of testbeds.

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Qualification Table: Conformity between radar design, drone design, and end-user requirements, and description of testbeds

D5.1v1	End-user requirements	Value	Radar design	Value	Design conformity with end-user requirements (Y/N)	UAV design	Value	Design conformity with end-user requirements (Y/N)	Testbed design description	Criterion for satisfactory test result	Testbed requires radar-drone integration	Date of test	Month of test
1	END-USER REQUIREMENTS VS. SOUNDING MODE CAPABILITIES												
1.1.	**Subsurface structure imaging**		**Frequency range** *Equivalent wavelength* **Centre frequency** **Bandwidth**	30-300 MHz *1-10m* 80 MHz 10MHz	Y				**Frequencies** Frequency values to be checked in laboratory during radar construction using the appropriate instruments	Frequency values as expected	N	Jun - Sept 2022	M17-M20
1.2	**Permittivity** Rocks eps = 2-30 *Note: Variable soil moisture* *Note: Groundwater present/not present*	2-30	**Accuracy of detection of changes in permittivity (radiometric detectability)**	1 dB	Y				**Permittivity accuracy** Indoor and outdoor laboratory verification. Field calibration in flight (clear lake surface, flat desert area)	dB value as expected	Y	Oct 2022 - Feb 2023	M21-M25
1.3	**Required penetration depth** *Controlled by stratigraphic interface, faults, volcanic dykes*	0-15 m	**Depth of penetration**	2-50 m	Y				**Penetration depth** Theoretical models	Penetration depth as expected	N	Jun - Sept 2022	M17-M20
2	END-USER REQUIREMENTS VS. SAR CAPABILITIES												
2.1	**Surface imaging**		**Frequency** *Equivalent wavelength* **Centre frequency** **Bandwidth**	1.0-0.3 GHz *0.3 - 1 m* 435 MHz 40 MHz	Y				**Frequencies** Frequency values to be checked in laboratory during radar construction using the appropriate instruments	Frequency values as expected	N	Jun - Sept 2022	M17-M20
2.2	**Mapping/polarization** *Volcanic dykes, river beds, dunes, fan delta, other landforms*	HH, HV, HH	**Planned polarization**	HH, HV, VH, VV	Y				**Evaluation of datasets obtained in all the polarization modes** Calibration in flat desert region	Satisfactory image quality in the 4 polarization modes	Y	Oct 2022 - Feb 2023	M21-M25
2.3	**Reflectivity**	Reflectance 0.1 - 0.95	**Sigma0 (reflectivity) that can be detected**	Determined after test results	tbd				**Test of Sigma0** Characterized in lab using tests and models used to estimate performance	Satisfactory discrimination of reflectances for various surfaces	Y	Oct 2022 - Feb 2023	M21-M25
3	END-USER REQUIREMENTS VS. UAV CAPABILITIES												
3.1	**Autonomy required by scientific experiment** Maximum surface area covered in one fligh Required flight distance autonomy	Equiv. Grid: 1000 m x10 m x 15 15 km				**Flight autonomy** Nominal time of autonomy Nominal speed Nominal flight distance autonomy	25 min 10 m/s 15-17 km	Y	**Flight autonomy** Weighted (3 kg) drone flight test	Nominal flight time, speed and distance	N/Y	tbd	tbd
3.2	**Atmospheric environment** Atmospheric temperature during campaign Maximum wind expected during campaign	45°C 11 km/h				**Atmospheric environment tolerance** Maximum external temperature allowed Maximum wind speed allowed (data quality degraded and autonomy reduced)	50°C 40 km/h	Y	**Environmental tests** Theoretical thermal test Weighted (3 kg) drone flight test	Drone components unaffected by maximum temperature Acceptable flight stability	N N/Y	Jun - Sept 2022 tbd	M17-M20 tbd
4	END-USER REQUIREMENTS VS. RADAR AND UAV CAPABILITIES												
4.1	**Required sounding radar spatial resolution** Along-track resolution Cross-track resolution Flight altitude above ground*	20 m 200 m 50-150 m	**Spatial resolution in sounding mode** Along-track resolution Cross-track resolution Flight altitude above ground, sounding mode	20 m 200 m 120 m (tbc)	Y Y Y	**Flight altitude range** Flight altitude range above ground	50-300 m	Y	**Spartial resolution testing, sounding mode** Theoretical models Theoretical models Post-integration flight test	Resolution as expected Resolution as expected Nominal flight altitude and data resolution	N N Y	Jun - Sept 2022 Jun - Sept 2022 Oct 2022 - Feb 2023	M17-M20 M17-M20 M21-M25
4.2	**Required SAR spatial resolution** Along-track resolution Cross-track resolution Flight altitude above ground*	5 m 5 m 50-150 m	**Spatial resolution in SAR mode** Along-track resolution Cross-track resolution Flight altitude above ground, SAR mode	4.6-4.7 m 3.8-6.9 m 100 m	Y Y Y	**Flight altitude range** Flight altitude range above ground	50-300 m	Y	**Spartial resolution testing, SAR mode** Theoretical models Theoretical models Post-integration flight test	Resolution as expected Resolution as expected Nominal flight altitude and data resolution	N N Y	Jun - Sept 2022 Jun - Sept 2022 Oct 2022 - Feb 2023	M17-M20 M17-M20 M21-M25
4.3	**Geolocation**		**Geolocation**	Independent GPS	Y	**Geolocation**	Independent GPS	Y	**Geolocation** GPS recording obtained during post-integration flight test	GPS measurements consistent in both devices	Y	Oct 2022 - Feb 2023	M21-M25
	Scientific requirements	Value	Radar design	Value	Design conformity with drone requirements (Y/N)	UAV design	Value	Design conformity with radar requirements (Y/N)	Testbed design description	Criterion for satisfactory test result	Testbed requires radar-drone integration	Date of test	Month of test
5	RADAR REQUIREMENTS VS. UAV CAPABILITIES												
5.1			**Connectivity to drone** Electric interface with radar	4 pinned XLR adapter	Y	**Connectivity to radar** Electric interface with radar	XT60 + 4 pinned XLR adapter	Y	**Connectivity of interfaces** Drone/radar connectivity	Successful measured connection	Y	Oct 2022 - Feb 2023	M21-M25
5.2			**Mounting** Physical adaptation to drone	N/A	N/A	**Mounting** Physical adaptation to radar	Two customised mechanical elements	Y	Post-integration flight test	Nominal flight	Y	Oct 2022 - Feb 2023	M21-M25
5.3			**Radar weight** Total weight (incl. antenna)	3 kg	N/A	**Radar weight** Maximum allowed radar weight (reduced autonomy)	4 kg	Y	**Radar weight** Measurement of radar weight	Weight as expected	N	Jun - Sept 2022	M17-M20
5.4			**Instrument shape and mass distribution** Instrument symmetry and location of centre of mass	Limited shape asymmetry and uneven mass distribution due to building of side antenna (SAR mode) in light materials	Y	**Instrument shape and mass distribution** Drone symmetry and location of centre of mass	Symmetric and centre of mass located at the drone geometric centre	N/A	**Aerodynamics** Post-integration flight test	Nominal flight altitude, time, speed, and distance	Y	Oct 2022 - Feb 2023	M21-M25

* UAV flight regulations in Morocco: flight altitude: min 50 m over people, max 150 m above ground; distance to nearest airport: 8km; maximum drone weight: 25 kg

red: to be confirmed