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TEST PLAN AND VALIDATION METHODS

FLAIR - FLying ultrA-broadband single-shot InfraRed Sensor
GA732968

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Abstract:
This document presents a description of the test and validation activities to be performed in the scope of project FLAIR. The three phases of test are described: phase 1 will consist of structural trials on the UAV to prepare for the sensor integration; phase 2 will consist of motion tests with the sensor, verifying its operation in a moving vehicle; phase 3 will consist of operational tests to be performed with the airborne prototype platform.

Document History

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Executive Summary

Deliverable 2.4 contains the information regarding the final test and validation procedures to be implemented in WP4, WP5 and WP6. This document presents a description of the test and validation activities to be performed in the scope of project FLAIR. The consortium plans to execute the FLAIR tests over three phases. These phases of test are described in the document and summarized here:

- Phase 1 will consist of characterizing the performance of the spectrometer in a laboratory environment;
- Phase 2 will comprise structural trials on the UAV to prepare for the sensor integration and motion tests with the sensor, verifying its operation in a moving vehicle;
- The last phase, phase 3, will consist of operational tests to be performed with the airborne prototype platform.

The testing procedures mentioned herein are described in general terms as this document is more concerned with the testing approach rather than with the actual tests. The reasoning behind this is that at this moment of the project, there are simply too many unknowns to adequately design final test setups and test conditions. The detailed definition and description of the test setups, test conditions, excitation inputs, expected outputs and success criteria will be the subject of subsequent work packages, namely WP4, WP5 and WP6. The content of this report is therefore focused on the initial identification of the main tests the consortium will pursue to validate the FLAIR sensor and concept and how the tests will be organized. The types of tests to carry out and parameters and characteristics and phenomena to measure are also described. Whenever possible the consortium already provides details on the test setups.

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List of Acronyms

Acronym	Meaning
ANSP	Air Navigation Service Provider
OFAC	Office Fédéral de l'Aviation Civile
Ppmv	Parts per million by volume
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle

Table 1 – List of acronyms.

1 Introduction

Task 2.4 of FLAIR is dedicated to the definition of the tests and evaluation methods for the developed sensor and for the aerial platform it will be integrated in. The careful planning of all the relevant tests and performance evaluation methods ensures the full functionality of the FLAIR sensor system. This document reports upon the work performed within Task 2.4. The reader should note that the detailed definition and description of the test setups, test conditions, excitation inputs, expected outputs and success criteria will be the subject of subsequent work packages, namely WP4, WP5 and WP6. The reasoning behind this is that at this moment of the project, there are simply too many unknowns to adequately design final test setups and test conditions. Rather, the content of this report is focused on the initial identification of the main tests the consortium will pursue to validate the FLAIR sensor and concept and how the tests will be organized. The types of tests to carry out and parameters and characteristics and phenomena to measure are also described. Whenever possible the consortium already provides details on the test setups.

In agreement with the work plan of FLAIR, the tests and evaluation methods as defined in Task 2.4 can be subdivided into three phases:

1. Based on the preparatory investigations in WP3 (Laboratory Spectroscopy) and the development and assembly of the various subsystem elements of the sensor module within WP4, the vital functionality of the developed sensor prototype is tested (T4.8).
2. In a second phase, the sensor prototype will be fitted to the UAV and the functionality of all interfaces, data storage and transmission, as well as the influence of motion and vibration on the sensor performance is tested in controlled environments (T5.1 and T5.2).
3. Finally, tests will be performed to characterize the prototype sensor module under real conditions through fixed measurements on the roof of an air quality measurement station next to the air inlet of reference instruments. In addition, the functionality of the complete FLAIR sensor system will be evaluated during a well-defined test flight (T6.1). The main goal of this testing phase is to ensure that all subsystems of the FLAIR sensor are working properly and as expected. The test flight within T6.1 will also serve as a preparation for the demonstration in T6.2. Several arrangements for T6.2 in terms of logistics (e.g. location, duration, how to transport the prototype, etc…), issuing invitations, obtaining flight authorizations and tasking necessary personnel to carry out the demonstration will be required and some of these can already take place when setting up and executing the tests of T6.1 (e.g. flight authorizations).

It might be necessary to iterate between the three above phases due to modifications and optimization of the sensor module and the airborne platform in order to achieve the highest performance of the FLAIR sensor system. The phases 1-3 are described in detail in sections 3 to 5.

2 Procedure

This report was written by the participants listed in the table above under the lead of EMPA. More specifically, the following steps were taken:

- establishment of the structure and first report draft (10.05.2017)
- teleconference (14.07.2017)
- input from all participants received (10.08.2017)
- second report draft completed (18.08.2017)
- final feedback from all participants (25.08.2017)
- final report completed (06.09.2017)

2.1 Laboratory tests

The tests of the FLAIR system in a laboratory environment include

1. Preliminary tests of the standalone sensor at integration stage (corresponds to Task 4.8). These tests are detailed in section 3.1 below.
2. Preliminary tests of the sensor mounted on the UAV, including all interfaces (corresponds to Task 5.2). These tests correspond to phase 2 and are detailed in section 4 below.

2.2 Field tests

The field tests of FLAIR correspond to the 3rd phase of testing and are described in section 5.

3 Phase 1 - Tests of spectrometer performance

The FLAIR system consisting of a 2D spectrometer sensor mounted on a UAV will be tested and characterized at different stages first in a laboratory environment and second during field tests.

3.1 Characterization of the prototype

Within WP3, missing and needed spectroscopic parameters are determined through test measurements using laboratory-style setups. The results of these laboratory tests will feed into the definite design of the sensor system to be built in WP4.

The vital functionalities of the sensor prototype built in WP4 and operating in the spectral window from 2-5 μm will be tested at CSEM laboratories through a series of testing routines first without any gas absorption. These tests will mainly focus on checking the good operation of the standalone sensor powered by the same power supply unit, or equivalent, available on the UAV as well as the control computer (see deliverable D2.3) such as:

- Power interfaces, current and voltages stability and inrush current performance tests.
- Communication tests between the control computer and all the subsystems (interfaces check), including data storage and processing algorithm.

- Temperature stabilization tests using a thermal chamber
- Potentially vibration tests

Then, the resolution of the instrument will be tested with single species such as CO_2, CH_4, CO, O_3, NH_3 and/or HCl at high concentration, possibly as a function of pressure in the multipass cell. The effects of water vapour absorption as a function of the multi-pass cell mirror's tunable temperature will be tested as well. Preliminary tests at high pressure with reference cells filled with CO2 and NH3 can be done at CSEM.

In a second phase, the sensitivity of the sensor will be assessed at RU laboratories.

- The RU will connect the sensor to diluted mixtures of gases for CO_2, CO, methane and HCN. Premixed, certified bottles with typical ppmv mixtures of that specific gas in nitrogen will be used.
- The pressure dependence within the absorption cell will be evaluated for the detectivity of specific gases. Due to the flying conditions, the air flow speed will change and as such also dynamic flow pressure fluctuations will exist.
- Dilution experiments will be performed down to the low ppb volume mixing ratio to test the linearity of the sensor with the applied gas concentration and to determine the detection limit for that gas.
- Spectroscopic interference will be investigated with other gases (especially water vapor), and the memory effect of the sensor will be tested.
- In an environmental climate room, temperature changes will be applied to the sensor to test the sensor's performance in changing temperature conditions.

In both resolution and sensitivity test protocols, a gas inlet system (provided by TEK-AS) similar to the one that will be implemented on the UAV nacelle (see deliverable D2.3) will be used and tested at different flow rates.

Tests within the second window at 8-12 µm will be performed independently on a lower TRL setup, using the same procedure as described above.

4 Phase 2 - Preliminary tests of sensor on UAV

The vital functionalities of the integrated sensor prototype fitted to the UAV will be tested at TEK-AS premises. In these tests, the following fundamental behavior of the UAV/sensor assembly will be surveyed.

4.1 Sensor integration

This initial test and validation phase will be focused on the structural evaluation of the UAV's cargo bay and its adaptation to host the sensor module. The objective of this series of trials

is to verify that the modifications performed on the UAV will enable a smooth integration of the two systems. Furthermore, it will also be necessary to validate the electronic and electric interface between the two systems. These trials will guarantee that the sensor module can be safely powered by the aircraft during the complete time of the mission. Besides the power evaluation, it must also be certified that the aircraft can communicate with the sensor module, enabling the correct reception of data from the sensor, storage and transmission to the ground. On the other hand, it is crucial to verify the transmission of commands from the ground to the sensor.

The first few tests of this phase can be initiated as soon as a final design is achieved in WP4 for the size and weight of the sensor module. With this information, it will be possible to produce a dummy sensor module which will have the volume, mass and mechanical interface characteristics of the final sensor. This dummy module will be used to test the fitting of the sensor inside the modified cargo bay of the aircraft by testing the mechanical assembly of the dummy module in the UAV. The notches that will hold the sensor in position inside the aircraft will also be tested. This enables the verification of the sizing and mechanical tolerances between the sensor module and the aircraft's cargo bay.

Besides, the above mentioned dummy module will be used to test the aircraft's centre of mass variation with the sensor assembled, as well as all the inertial characteristics of the aerial platform, potentially enabling aerodynamic tests, if considered relevant.

The performed tests include the validation of the sensor's electric and electronic interface with the aircraft (T4.8 and T5.1). The sensor electronic connections will be tested, assuring that all the physical connections are compatible and also that the electronic protocols for data transfers are in accordance. Furthermore, the transmission of data will be tested. The test measurements will verify

- the correct reception of data from the sensor, storage and transmission to the ground
- the aircraft's communication with the sensor module
- the transmission of the data gathered by the sensor to the ground station
- the transmission of commands from the ground station to the aircraft and to the sensor.

4.2 Gas inlet system and mechanical tests

A further suite of tests will target the investigation of the behavior of the designed gas handling or gas inlet system (T4.3) as well as the performance of the FLAIR sensor when operated under mechanical stress. The objectives of this test phase are to verify if the sensor's nominal operation is maintained when the sensor is in motion relative to the air and under a vibration load caused by the aircraft's engine as well as the flight environment.

Firstly, the sensor will be tested in motion. This procedure will consist on assembling the sensor on top of a road vehicle in order to subject the sensor to airflows with the same

velocity of the aircraft in flight, *i.e*. about 90 km/h. This test will simulate the effects of moving air near the sensor inlet. The objective of this trial is to verify the correct measurement of the air pollutants even with an air flow in the sensor inlet. In case this test measurements lead to unsatisfactory results, the gas inlet will be re-designed accordingly.

After the final sensor has been correctly assembled in the UAV's cargo bay in T5.2, the operation of the sensor, including data gathering and transmission, will be tested on the ground with the aircraft's engine in operation. This test will enable the verification of the influence of the vibration of the engine on the operation of the sensor. From this test it will be possible to validate if the sensor is subjected to noise, loss of accuracy or precision, as well as if the vibration produced by the engine will have a damaging effect on any of the sensor's components.

5 Phase 3 - Field test of sensor module

The FLAIR sensor system will be operated at the sensor test facility on the roof of the suburban air quality monitoring station on the premise of EMPA in Dübendorf. It will be run for several days next to the inlet of high precision reference instruments. These parallel measurements are used for the determination of the sensitivity and the measurement uncertainties of the FLAIR sensor system for the identified target gas species (CO_2, CH_4, CO and O_3, see FLAIR Deliverable 2.1) under real world conditions.

Beside the FLAIR sensor system, the particle sensors that will additionally be mounted on the UAV for the demonstration measurements in WP6 will be tested and characterized through field measurements at the sensor test facility in Dübendorf, where reference particle instruments are available.

The third and last phase of tests and validation procedures will consist of operational flights with the full system assembled. The objective of this test phase 3 is to validate the system and all the components developed and modified within the scope of Project FLAIR. The detailed examination and validation activities to be performed will have as a final objective to assure that the system meets the requirements defined within the project (outputs from WP2).

This series of tests will be performed in Switzerland in the surroundings of Beromünster tall tower. At the tall tower atmospheric research site in Beromünster, precise measurements of atmospheric trace gases are available from different heights (12m, 45m, 72m, 132m and 212m above ground).

The complete assembled system will be operated in the airspace near the tower in order to measure the pollutants present. The objective of the test will be to gather data from various points surrounding the tower, in order to compare the measurements obtained with the UAV with the measurements from the reference instruments on the tower.

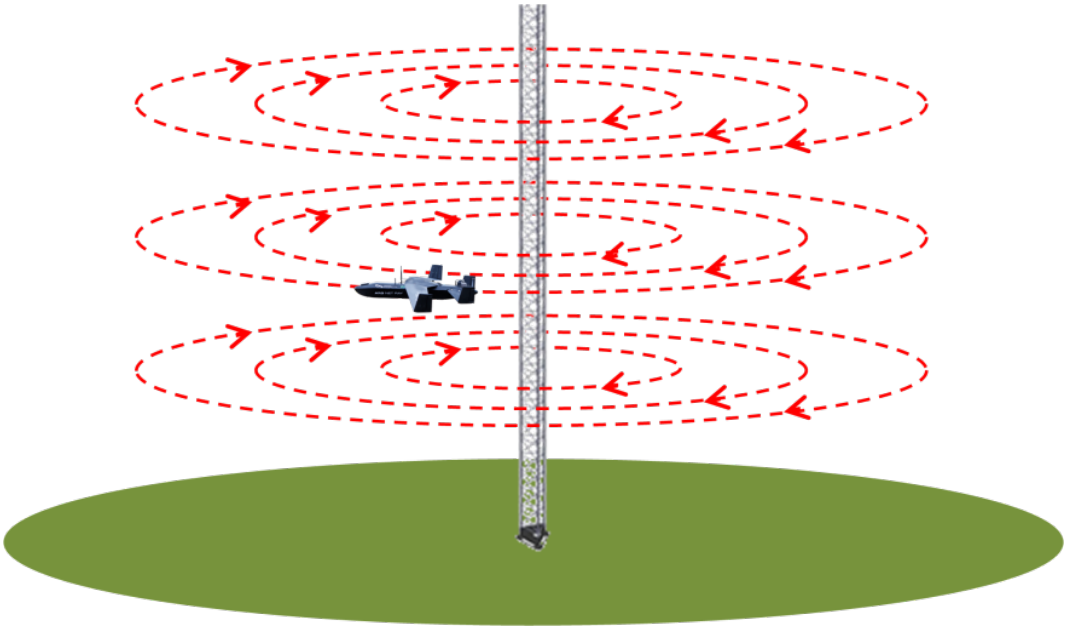

Figure 1 - Flight trajectories for the final test of the FLAIR system and demonstration.

The flight profile for this test is shown schematically in Figure 1. Depicted in the mentioned figure are the various concentric flight trajectories that the aircraft equipped with the FLAIR sensor will perform (in red) around the Beromünster tall tower. The flight plan is to follow a circular horizontal trajectory concentric on the tower gathering data in various points along the circle. Several trajectories will be performed, varying the altitude of the circle plane and the circle radius, from one circle to another.

The sensor will be operated during the circular portion of the flight path, leaving it on standby mode during the transfers between each circumference. This method for operating the sensor will be more power efficient and, consequently, will allow for longer flights. After the data gathering operations, a spectrum of chemical species of pollutants will be analysed for each point of the trajectory, calculated with the GPS information from the aircraft. This data will then be compared with the data from the tower in order to evaluate the correct operation of the system.

The frequency at which the air is being measured by the sensor, the number of horizontal circumferences, and the variation of the radius of each circumference, are variables that will be defined depending on the weather conditions (mainly wind intensity and direction) and pollutant concentration during the day of the test.

This test phase will also serve as a demonstration for the system developed in the scope of Project FLAIR. A second campaign near the Nabel highway area is also considered and will follow a similar approach. Its execution will depend on obtaining the required authorizations from the Swiss national authorities. The flight trajectories will be proposed in detail after the first meetings with the Swiss aviation authorities take place, but it's possible already to estimate that the UAV will probably fly "S" of increasing length perpendicular to the highway taking measurements that allow the preparation of a profile of measurements with distance to the highway at various altitudes. Furthermore, all the flight activities will be performed in coordination with the Swiss ANSP (Aerial Navigation Service Provider) and validation of the Swiss federal office for civil aviation - Office Fédéral de l'Aviation Civile (OFAC).

6 Summary and conclusions

A high level description of the test and validation activities to be performed for evaluation of the overall behaviour and performance of the FLAIR sensor system is given. This description serves as a guideline and a benchmark for the entire sensor and UAV validation process.

Based on the analysis of the expected sensitivity of the FLAIR sensor system and the relevance of the identified feasible gases for atmospheric observation, it is suggested that the demonstration application within WP6 will focus on CO_2, CH_4, CO and O_3.

Owing to their spectral signature and atmospheric relevance, N_2O and SO_2 have been identified as additional potential target gases for sensor characterization, optimization and validation. Furthermore, NH_3 and HCl may be investigated in dedicated laboratory tests because they have strong spectral characteristics and are relevant in many environmental and industrial processes.