Development and qualification of instrumented unmanned planes for turbulence observations in the atmospheric surface layer

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INTRODUCTION

In "Laboratoire d'aérologie" (Toulouse –France)**,** two Unmanned Aerial Systems (UASs) of different size have been developed .
The first one, called "**OVLI-TA"**, is a small drone (UAS) of 3kg including the payload. After wind tunnel calibrations, the drone flight tests were conducted in Lannemezan site-France. The drone then participated to the international project DACCIWA (Dynamics-Aerosol-Chemistry-Clouds Interactions In West Africa), in Savè, Bénin.
The second one is so called **"Boreal" drone**, which weights 20 kg and can embark 5 kg of sensors and IMU with data fusion.

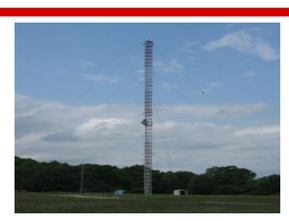
OBJECTIVES

- Develop, instrument and qualify the two UASs for turbulence observations in the atmospheric boundary layer.
- Present the instrumental packages of the two UASs.
- Compare data of OVLI-TA with data of tower and conclude about the robustness of drone measurements.

SITES and DATA:

- Data from 60 m tower of Lannemezan-site which is equipped with sonic anemometers of 10Hz (3 available levels: 30m,45m and 60m).
- DATA from OVLI-TA drone which has flown in Lannemezan (flight tests) and Bénin (DACCIWA).

DACCIWA SITE, in Savè, Bénin



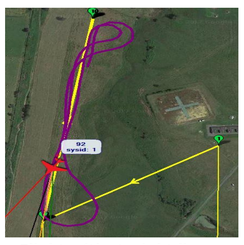
Picture of the instrumented Mast of 60 m at Lannemezan Site

Methods and UASs missions:

We calculate the wind speed by subtracting the airspeed (5-hole probe) from the ground speed (GPS), using equations established by Lenschow(1986) , and by focusing on the selected sequences where the drone flies in a straight line.

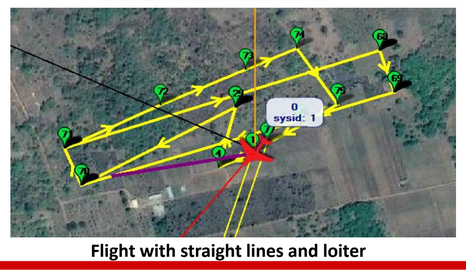
Flight PATTERNS:

A-LANNEMEZAN Site:



Flight with straight lines

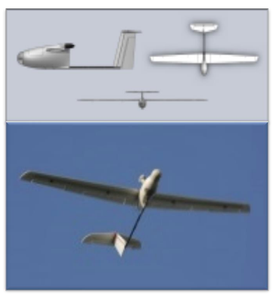
B-DACCIWA Site:



Flight with straight lines and loiter

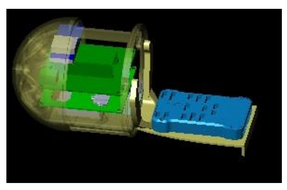
Characteristics of OVLI-TA Unmanned Airplane Vehicle:

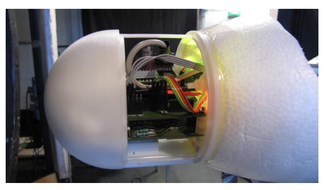
- Electrical propulsion.
- Cruise Speed : 60 km/h – 100 km/h (16,5 m/s- 28m/s).
- Wingspan : 260 cm - Wing area : 3903 cm²- Fuselage. Length : 114 cm.
- Dry weight : 1.25 kg -Loaded weight : 2.26Kg (1 kg of battery/payload).
- EPO Wings and fuselage construction.
- flight times : 1-2 hours autonomy.

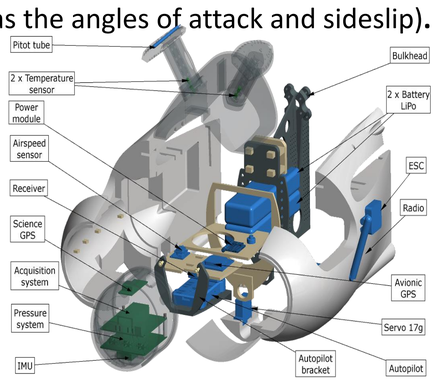


Electronic devices of OVLI-TA used for turbulence measurements:

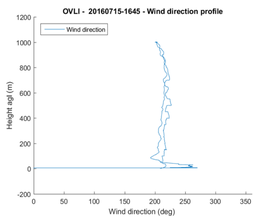
- **µ**SD card : **100 Hz.**
- 3 **Temperature/humidity sensors** SHT75 : 2 slow of **2,5 Hz** and 1 faster of **10 Hz**.
- 1 **IMU** ADIS16448 analog device (**100 Hz**) : - Triaxial digital gyroscope.
  - Triaxial digital accelerometer.
  - Triaxial digital magnetometer.
  - Digital barometer.
  - Embedded temperature sensor.
- **"5-hole" probe in the drone nose**: 3 **Differential pressure transducers** (HCEM10) : **100 Hz** (Measures the air speed, as well as the angles of attack and sideslip)**.**
- 1 **GPS** : **5 Hz**
- Pitot tube (Static pressure).
- 3DR **Pixhawk Autopilot :** - GPS (5 Hz).
  - IMU (50 Hz).



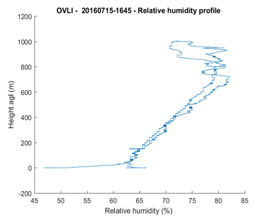




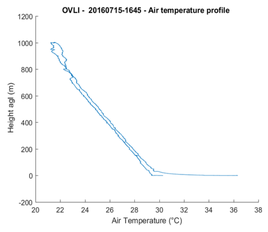
DACCIWA Results: Flight example



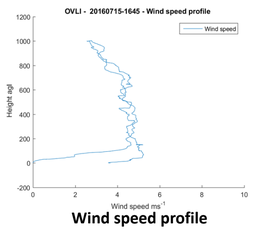
Wind direction profile



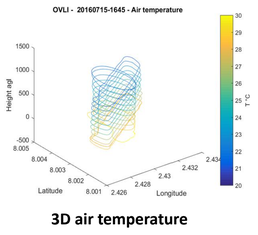
Relative humidity profile



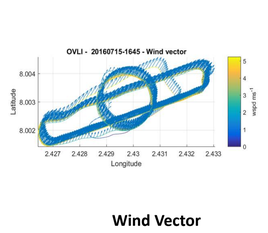
Air temperature profile



Wind speed profile



3D air temperature



Wind Vector

References

- Lenschow, Donald.H. Aircraft Measurements in the boundary Layer, In , Probing the atmospheric Boundary Layer, Lesnschow,Donald. H,39-55. Boston: American Meteorological society ,1986.
- Gomez Kuri, Z. Atmospheric turbulence study utilizing a five-hole probe on an unmanned aerial vehicle (UAV), Master thesis.

Acknowledgment :
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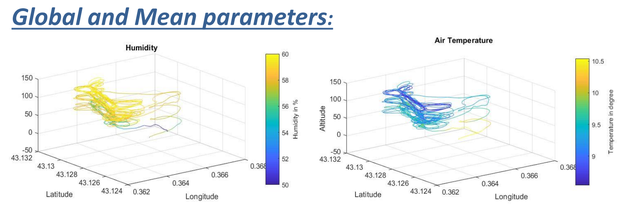
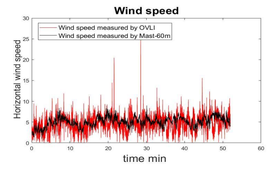
Lannemezan flight Results:

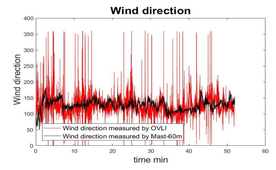
Global and Mean parameters:



Humidity , Air temperature for 1 h flight

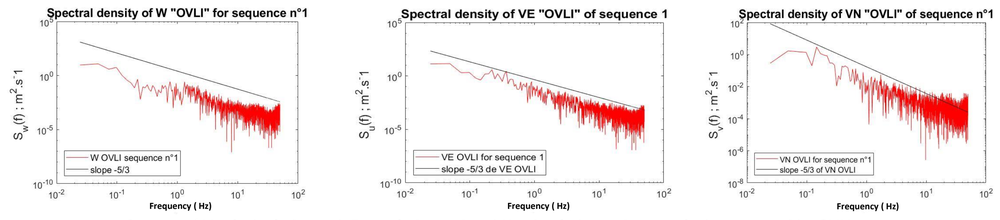


Comparison between Wind Speed for 1 h flight measured by OVLI and by Mast-60m

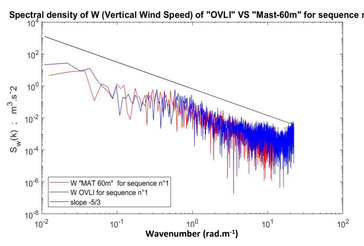


Comparison between "Wind Direction towards which the wind is blowing" measured by OVLI and by Mast-60m

Turbulence:

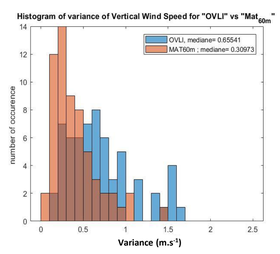


Spectra of Vertical wind speed, East wind speed and North wind speed respectively measured by OVLI



Spectra of Vertical wind speed measured by OVLI and Mast-60m

-In order to convert the frequency scales to wavenumber ones, we use for OVLI the air speed and for the mast-60m the wind speed (Taylor hypothesis): $k = 2\pi f/\bar{u}$

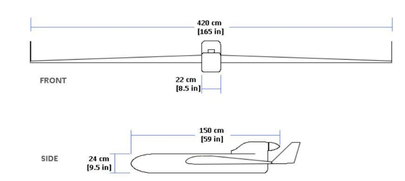


Histogram of the variance of vertical wind speed

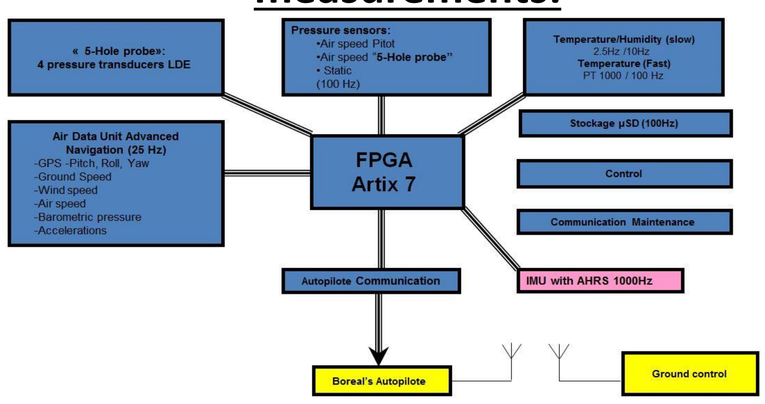
- This 1 h flight is composed of 61 sequences of straight line flight which last 30s at constant altitude.
- The statistic comparison between the data of mast, and the measurement of OVLI-TA shows a good agreement.

Characteristics of BOREAL Unmanned Airplane System:

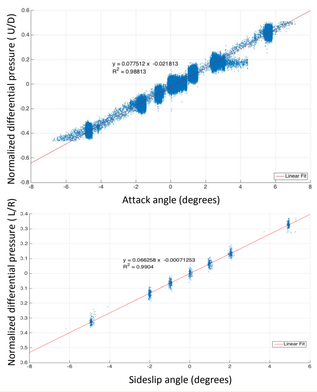
- Combustion engine.
- Cruise Speed : 70-130 km/h (19-36m/s).
- Wingspan : 420 cm.
- Fuselage Length : 150 cm.
- Dry weight : 20 kg.
- Loaded weight : 5Kg of payload.
- Flight times : 10 hours autonomy.



Electronic devices of BOREAL used for turbulence measurements:



Wind tunnel calibrations of the 5-hole probe of Boreal (GOMEZ KURI, Z)



$$\alpha = k_\alpha^{-1} * \widehat{\Delta P_\alpha}$$

$k_\alpha = 0{,}0775$

$$\beta = k_\beta{}^{-1} * \widehat{\Delta P_\beta}$$

$k_\beta = 0{,}0662$

k: sensitivity factor

Perspectives :

- ❑ Flight tests for Boreal's drone in Lannemezan.
- ❑ Measurements campaign in equipped sites (Masts and towers) with longer straight lines flights.

Conclusion :

- The OVLI-TA drone is capable of turbulence measurements.
- Boreal's drone will allow us to get a better spatial resolution, and is robust enough to fly in turbulent conditions for longer time .