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USING UAV-LTA FOR ENVIRONMENTAL MONITORING

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ABSTRACT. UAV (unmanned aerial vehicles) technologies are currently mature proven by their use in both civilian and military fields. Atmospheric monitoring involves certain technical and operational conditions and limitations of UAVs, especially in situations involving static and quasi-static flight, and the performance level of the sensors determines the degree of confidence in data samplings in the interest area. Aerodynamic optimization aspects of airship UAV result in enhanced flight characteristics and performance. The article proposes to present and analyze a technical solution for the use of blimp UAVs to monitor aerodynamic atmospheric and environmental conditions of this air vector, and a presentation of the types of sensors (navigation and mission).

Keywords: environmental sensors, UAV-LTA, flight data, aerodynamics analysis.

Acronyms and symbols:

GCS	*ground control station*	*LTA*	*lighter than air*	*FPV*	*first visual person*
NBC	*nuclear, bacteriologic, chemical*	*VOC*	*volatile organic compounds*	*EO-IR*	*electro-optical infrared*
AP	*Automatic pilot*	*CG*	*mass point centre*	*Tx*	*transmitter*
VLM	*vortex lattice method*	*TRL*	*technology readiness level*	*IMU*	*inertial measurement unit*
VOC	*Volatile organic compounds*	*UAV/S*	*unmanned aerial vehicles/systems*	*Rx*	*receptor*
C_n	*yaw coefficient*	*alpha*	*incidence angle*	*G*	*mass*
C_L	*lift coefficient*	C_D	*drag coefficient*	C_m	*pitch coefficient*
C_l	*roll coefficient*				

1. INTRODUCTION

Atmospheric monitoring requires certain conditions and technical and operating limitations that can be met by the UAV, especially in situations involving static and quasi-static flight data. The performance level of onboard sensors determines the degree of confidence in data capture in areas of interest. Vertical air quality monitoring can currently use unmanned aerial platforms instead of meteorological balloons, providing large quantities and wider data spectrum, such as chemical compositions, electromagnetic spectrum (EO-IR, ultraviolet) or sound. These data can be processed onboard, on the ground (GCS) or later by end users.

In environmental monitoring, current research is focused on the acquisition and/or analysis of air, water and soil samples (Yaoa et al., 2018; Gallacher, 2016; Kantora et al., 2001; Chwaleba et al., 2014). For example, water samples are required by the petroleum industry to respect with environmental regulations or data collected from monitoring natural waterways in proximity to intensive farming areas (e.g. water sampling for nitrate leakage analysis).

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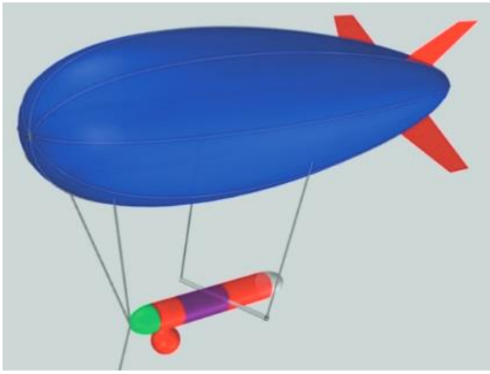
The approach to acquisition and analyzing data with UAVs can improve the efficiency of missions by eliminating the use of classical surface vectors although current models are limited to normal atmospheric conditions and to stationary water or slow water courses. Samples can be collected during the movement in the proximity of water or after landing using multi-copter, fixed wing, inflatable-air wing (airship). Mission sensors can acquire data on temperature, conductivity (salinity), pH, dissolved oxygen and other environmental parameters, see figure 1a and 1b.

a.



b.

Fig. 1. Environmental data acquisition project - a. 30 foot blimp (Kantora et al., 2001), b. K28 aerostat (Yaoa et al., 2018).

Unmanned aerial vehicles using air quality assessment can perform data acquisition missions with temperature, humidity, air pressure, ozone (O3), atmospheric pollutants (CO, CO2, NO, NO2, SO2, NH3, CH4) and powders in suspension (PM 1.0, 2.5 and 10), (https://www.robofun.ro/senzori). Use of UAVs can be useful for sampling air quality over a large area for a short period of time (e.g. industrial or civil infrastructure pollution points) by vertically sampling at a single GPS location or near the point of interest. A direction useful for assessing atmospheric and weather pollution at ground level or low altitudes (e.g. PM10) by atmospheric transport models (wind) to optimize the location of future infrastructure objectives (tourism, wind farms, farms) or reduce the level of pollution in urban, industrial and offshore areas.

The objective of the proposal is to use the regional and national of a UAV-LTA on missions of air quality monitoring to provide data (primary or processed) required users area central and local authorities for measures on improving living conditions in areas of interest.

2. UAV LTA – PROPOSAL

2.1. UAV-LTA

Based on a series of experimental activities performed on the ground operation of the UAV-LTA and in a calm atmosphere, we can advance the proposal for an airplane wing concept (airplane wing concept) that is designed for indoor and outdoor flights outdoor in poor wind conditions for didactic, commercial and scientific research in multidisciplinary and transdisciplinary fields.

The blimp is a 2017 design, with a polyurethane envelope and equipped with vectorized electric propulsion and four empennages, see Figure 2 and Table 1, (Prisacariu et al., 2018a; https://www.sparkfun.com/datasheets/Sensors/gp2y1010au_e.pdf). The air system contains the blimp type, a portable GCS and a manual docking device. UAV operations can be made in the visual range or FPV (first person viewer) beyond the visual range (by the automatic pilot/GPS), depending on the power of the radio-electronic equipment.

Fig. 2. UAV- LTA blimp, ((Prisacariu et al., 2018a)

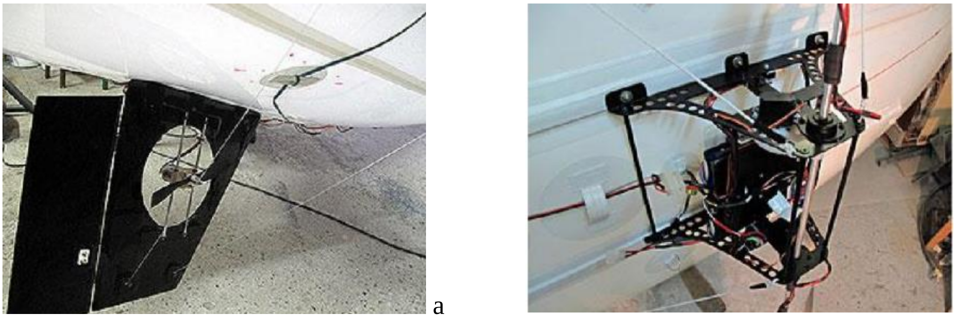
The air vector is radio-controlled using a 6-channel (2.4 GHz) RC system, 433 KHz telemetry (100 mW) and a 5.8 GHz image, the technical features are highlighted in Table 1. The UAV-LTA is equipped with 3 motors electric: 2 main brushless propulsion motors with Y axis (60°) vector and a Z axis of rotation, see Figure 3a and 3b.

Table 1. ***Features and flight performances (https://www.sparkfun.com/datasheets/Sensors/gp2y1010au_e.pdf)***

Features	Value	Features	Value
Length / diam.	5 / 1,7 m	Gas	Helium; loss 0,3% / day
Envelope / volume	polyurethane 100 microns / 8 m^3	Speed	0 ÷ 20 km/h
G. utile	1,2 kg	Autonomy	1 h
G. He	1,35 kg	Range	20 km
G. total	7 kg	Ceiling	3000 m
Motor	3 x electric	Battery	3 x LiPo 11,1 V de 3A
RC	6 canal	AP type	yes / GPS 48 channels

The polyurethane envelope is equipped with an overpressure valve and a rigid ventral fuselage mount system that allows the navigation of radio electronic (radio-controlled Rx and data acquisition sensors), batteries, and electric motors (see Figure 3b). The control surfaces are powered by 4 nano-type digital servo cameras and the vectoring of the motors is driven by a servo digital (miniature). The GCS includes the radio transmitter

(Tx), video and telemetry receiver, and a 7 inch monitor and laptop for programming, storing and post-data processing are used to view numerical and image information.



a b

Fig. 3. The hull blimp, a. electric motor for yaw axis, b. radio-electronic devices

The main type of mission that can be accomplished is static / quasi-static and low-speed data acquisition as follows: image data with EO-IR sensors (with navigation camera and high-resolution mission camera) or FLIR camera; telemetry data (numeric flight data); atmospheric data such as: temperature, humidity, dew point, air quality (dust particles), emissions (CO, NO), methane, hydrogen, flammable gases, wind direction and intensity; data on noise level, NBC data.

2.2. On-board sensors

The LTA vector sensors can be classified by usage: navigation and mission (Prisacariu, 2013). The navigation sensors used for command and 3D air vector control on the trajectory are for: speeds, altitude, temperature (inside), current (consumption, flight autonomy), flight position (accelerometers, magnetometers, magnetic compass), see figure 4a and 4b, (https://www.uradmonitor.com/; http://ardupilot.org/copter/docs/connecting-the-apm2.html).

a b

Fig. 4. Navigation sensors - a. IMU sensor, b. Pitot sensor (https://www.uradmonitor.com/)

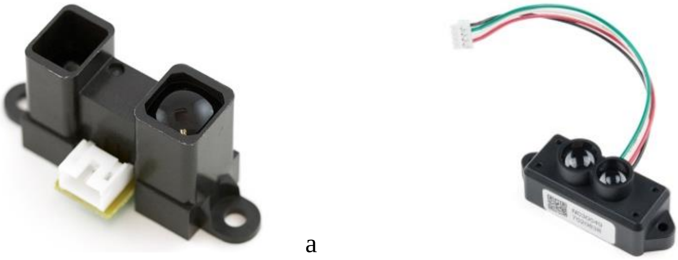
2.2.1. Navigation sensors

The automatic pilot is based on the IMU shield containing inertial sensors (gyroscope, accelerometer, and magnetometer) and altitude (pressure), see Figure 4a. The IMU is capable of ten independent measurements provided to a microcontroller or computer for calculating the absolute orientation (pitch, roll yaw) and altitude. Table 2 provides data on AltIMU-10 v5, (https://www.uradmonitor.com /wordpress/wp-content/uploads/2017/02/datasheet_a3.pdf) characteristics.

Table 2. ***IMU features, (https://www.uradmonitor.com /wordpress/wp-content/uploads/2017/02/datasheet_a3.pdf)***

Features	**Value**	**Features**	**Value**
Dimensions	2,54x1.27x0,25 cm	Weight	8 g
Voltage	2,5-5,5 V	Current	5 mA
Barometer sensitivity	260 mbar to 1260 mbar	Accelerometer sensitivity	±2, ±4, ±8, or ±16 g
Gyro sensitivity	±125, ±245, ±500, ±1000, or ±2000°/s	Magnetometer sensitivity	±4, ±8, ±12, or ±16 gauss
Communication port	I_2C	Data reading	16-24 biti

The UAV system is equipped with IR and LIDAR sensors (see Figure 5a and 5b).



a b

Fig. 5. Navigation sensors - a. IR sensor, b. LIDAR sensor (https://www.uradmonitor.com)

For radio-control the IR sensors measures distance in ultrasonic way and LIDAR are used to calculate distance from the ground or obstacles, see Table 3.

Table 3. ***Sharp sensor & LIDAR sensor features, (https://www.uradmonitor.com)***

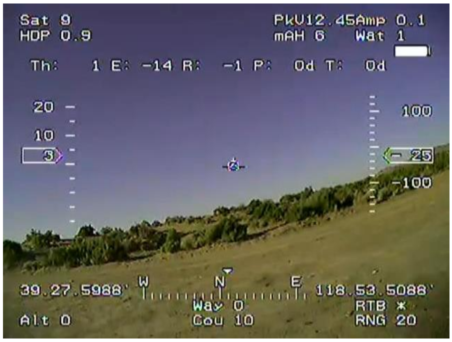
	Sharp sensor		
Features	**Value**	**Features**	**Value**
Dimensions	29.5×13×21.6 mm	Voltage	4,5-5,5V
Range	0,2 - 1,50 m	Current	33 mA
	LIDAR sensor		
Features	**Value**	**Features**	**Value**
Dimensions	42×15×16 mm	Voltage	5V
Range / resolution	0,3 - 12 m / 5 mm	Current	120 mA
Mass	6,1 g	Power consumption	0,12 W
Wavelength	850 nm	Operating temp.	-20 - 60ºC

The telemetry data transmitted to GCS overlaps an online image taken from a camera similar to Figure 6a and 6b, having the characteristics from Table 4 (https://www.uradmonitor.com).

Table 4. ***EO sensor features, (https://www.uradmonitor.com)***

Features	Value	Features	Value
Dimensions	32×32 mm	Voltage	12V (6-20V)
Sensitivity	0,2 lux	Current	50 mA
Mass	26 g	Frequency	60 Hz
Resolution	520 TVL	Operating temp.	-10 - 50ºC


a



b

Fig. 6. EO-IR sensor and telemetry data

2.2.2. Mission sensors

The mission sensors used to acquire and analyze atmospheric samples (see Figure 5) can be: open source (Arduino) with an average confidence level, see Figure 7a and 7b (Table 5 and 6) for qualitative measurements or professional stand-alone sensors (e.g. uRad monitor) for quantitative measurements (see Figure 8 and Table 7).

Table 5. ***Air quality sensor features, (https://www.uradmonitor.com)***

Features	Value	Features	Value
Dimensions	25×25 mm	Voltage	3,3 V
Temperature	-40 – 85º	Gas measure	CO, CO_2, pressure, humidity
CO range	0 -1187 ppm	CO_2 range	400 – 8192 ppm

a


b

Fig. 7. Open source sensor for missions – a. Air quality sensor, b. Dust sensor.

Table 6. ***Dust sensor features (Matese et al., 2015)***

Features	Value	Features	Value
Dimensions	46×30x17 mm	Temperature	-10 – 60°
Voltage	5 - 7 V	Current	20 mA
Measure	dust (PM 2.5), smoke		

The uRAD Monitor A3 model measures air temperature, barometric pressure, humidity and volatile organic compounds (VOC). A3 also contains a high-quality laser dispersion sensor that is used to detect particle concentration PM 2.5 in the air, (Chunhua and Kovacs, 2012; Ismael and Molina, 2014).

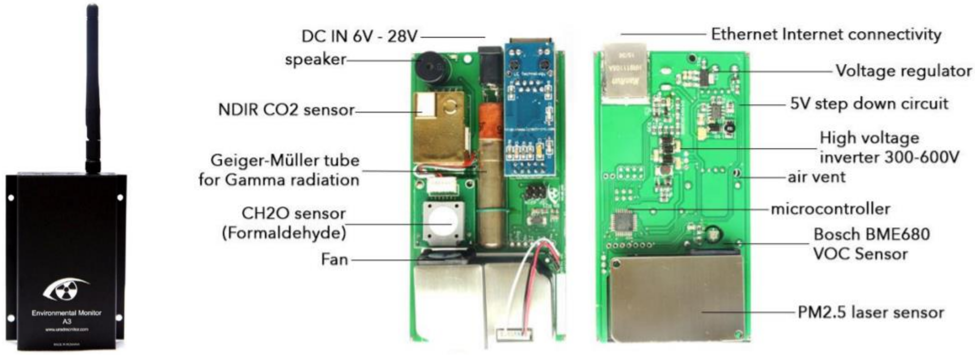


Fig. 8. uRAD monitor model A3, (Chunhua and Kovacs, 2012).

The model also contains: an electrochemical formaldehyde sensor, a non-dispersive infrared sensor to measure the CO_2 concentration in the air, and a Geiger SI29BG tube to detect gamma ionizing radiation and X-radiation, all of which are cooled by a built-in fan.

Table 7. ***uRAD Monitor A3 features (Chunhua and Kovacs, 2012)***

Features	Value	Features	Value
Dimensions	110×65x25 mm	Mass	170 g
Operating temperature	-40 – 100°	Connectivity	Wi-Fi, GSM, Ethernet LoraWAN
Voltage	6 - 28 V	Power TX	100 -250 mW
Range CO_2	400 -5000 ppm	Range VOC	0 -100 reducers/ 0 -10 oxidizers
Range formaldehyde	0 -5 ppm	Range PM 2.5	0 – 100 μg/m^3

2.3. Functional and flight test UAV-LTA

These included the preparation of the LTA vector for indoor and outdoor local tests through activities on: ensuring the buoyancy and static balance of the non-equipped flexible envelope; securing the static balance of flexible envelope equipped with propulsion and control-command systems; ensuring the operating parameters of the systems under archimedic conditions of the LTA anchored by the docking device; ensuring the operating parameters of the systems in archimedic conditions of the LTA in flight limits.

The tests that covered the above-mentioned activities were part of the MAPIAM project in 2017 entitled "*Modular Aircraft Platform for Intelligent Atmospheric Monitoring*", code PN-III-P2-2.1-PED-2016-1972, which is an experimental-demonstration project type PN III. The project resulted in the realization and testing of an aerostatic UAV (length 5 m, 8 m^3), the realization and testing of an airplane type UAV-LTA (span 1.8 m), the realization and testing of an integrated system of airplane UAVs coupled through the system which also constituted a patent proposal submitted to OSIM. These two UAVs have built test platforms for a flammable gas sensor to monitor air quality.

3. MISSION PLANNING

The mission describes the operation of the vehicle in a given region within a certain period of time to achieve a particular objective. Flight planning aims to create trajectories with physical and performance limitations of the aerostat, avoiding obstacles / collision with other vehicles and dangerous / avoidable regions and generates the trajectory and navigation of the LTA vehicle, (see Figure 9). The position, orientation and speed of the LTA vehicle is obtained from the sensors and the flight management system which has information on weather conditions and possible obstacles.

Fig. 9. Mission planning aspects with Mission Planner freeware (https://www.rc-zeppelin.com/outdoor-rc-blimps-5m.html).

To provision 3D movement, the LTA vector involves a number of resources (consumables / accumulators, time). For defining the trajectory, the sequence of configurations must be completed with the operating speed and altitude values. Optimal flight planning takes into account a number of criteria and runs in accordance with specific regulations and those related to the operating area.

A proposal on an atmospheric data acquisition mission can be seen in Figure 10.

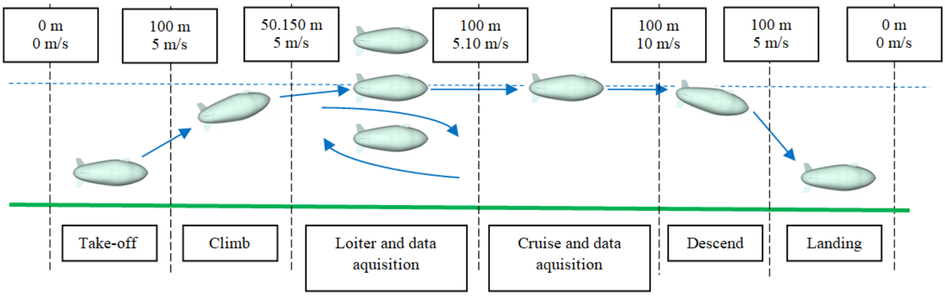


Fig. 10. Stages and profile mission

4. UAV-LTA analysis

To highlight the UAV-LTA flight qualities required for atmospheric data acquisition missions, we proposed a quasi-static analysis (very low speeds) with three instances of balance. Flight qualities determine the aerodynamic behaviour of the air vector that contributes to the improvement of atmospheric data (oscillations, balancing, vibrations).

The UAV-LTA vector has been transposed CAD concept using the XFLR5 freeware tool (https://www.pololu.com/product/2739) according to geometry and real mass characteristics see Figure 11.

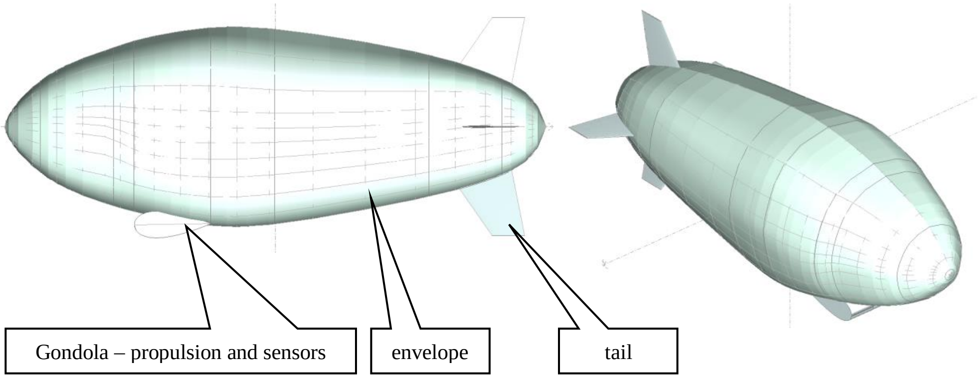


Fig. 11. LTA geometry for analysis

4.1. LTA balance

The definition of the balance includes the quantification of the masses of the component elements, for of simplicity we considered the total mass of the fuselage (flexible envelope, gas, tail) of 5.8 kg and the gondola weight of 1.2 kg (equivalent to the useful mass), which includes the radio electronic equipment, vectorized propulsion system (y-axis) and LiPo battery, see Figure 12.

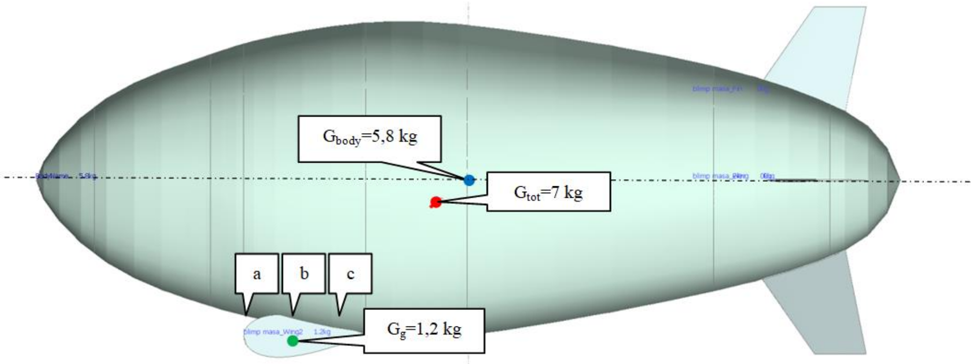


Fig. 12. LTA balance

In order to providing optimal aerodynamic behaviour depending on the flight conditions, the balance can be modified by repositioning the gondola in 3 positions (a, b, c) to the mass centre of the flexible tire, figure 12.

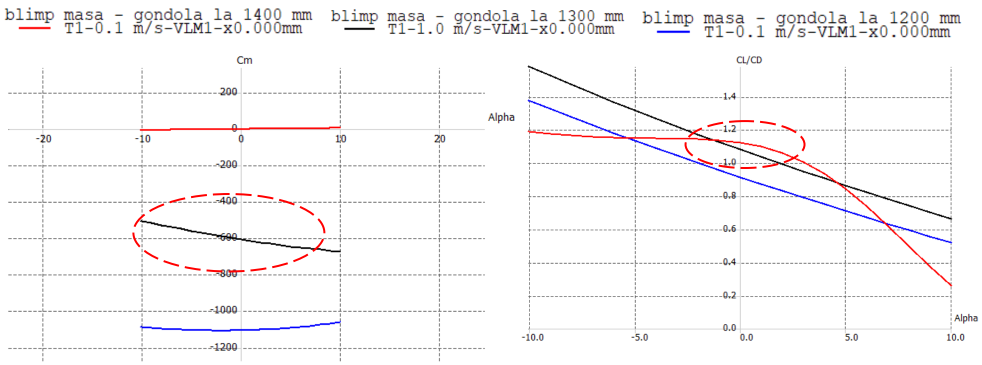
4.2. Aerodynamic analysis

To highlight the aerodynamic behaviour under different quasi-static flight conditions, numerical simulations were performed using the XFLR5 instrument (https://www.pololu.com/product/2739), the simulation parameters being highlighted in Table 9.

Table 9. ***Analysis parameters***

Features	Value	Features	Value
Speed	0,1 m/s	Incidence (alpha)	-10° ÷ 10°
Air density	1,22 kg/m^3	Method / iterations	3D panels-VLM / 200
Boundary conditions	Dirichlet	Polar type	Fixed speed

For a quasi-stationary flight (0.1 m/s) with locked commands and a calm atmosphere, we have the variation of the parameters corresponding to the 3 positions of the gondola, according to the graphs in Figures 13 and 14.

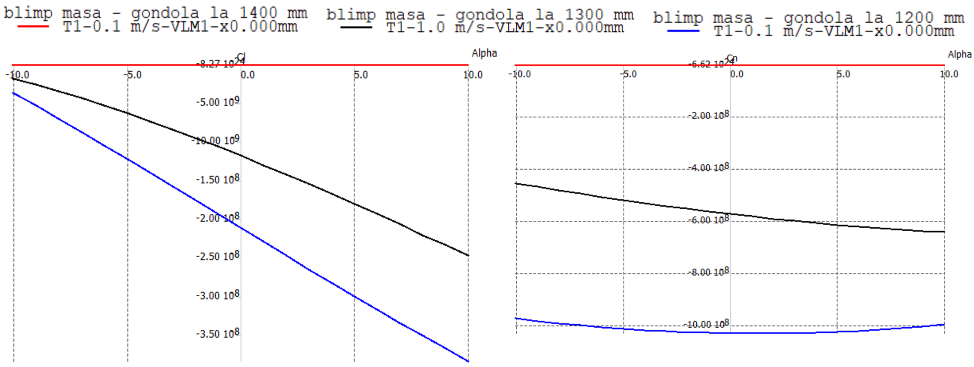


C_m vs alpha C_L/C_D vs alpha

Fig. 13. Aerodynamic parameters la 0,1 m/s

We observe a stabilized longitudinal behaviour (C_m) for the 1300 mm position and a better theoretical fineness at the gondola position of 1400 mm (most advanced) at zero incidence.

For Figure 14, we have the variation of the rolling coefficients (C_l) and yaw (C_n) depending on the incidence, the values in the modulus of the coefficients increase with increasing the corresponding distance of the position of the gondola to the CG of the flexible envelope.



C_l vs incidence C_n vs incidence

Fig. 14. Aerodynamic parameters la 0,1 m/s

So, in the quasi-stationary flight we can say that the LTA vector has an optimal behaviour around the 1300 mm position of the gondola for identical geometry and flight conditions.

The longitudinal and lateral stability of the flexible envelope offers favourable conditions for the air quality data collection process at the location of interest, according to the acquisition standards (lack of oscillations, reduced vibration, calibration conditions).

5. ADVANTAGES AND DISADVANTAGES OF THE PROPOSAL

Nowadays, monitoring and sampling of atmospheric and environmental data is done through teledetection platforms: terrestrial (fixed, mobile and portable), aerial (quasi-static and mobile) and aero spatial (mobile).

These platforms determine the use of certain sensors with certain attributes, such as: range, acquisition frequency and data synchronization, sensor coverage area. Use in UAV remote-sensing missions covers a multitude of civil and military fields from precision agriculture to monitoring conflict zones, (Guidelines for XFLR5 v6.03; Gallacher, 2016; Yaoa et al., 2018).

In this context, the proposed technical solution brings a number of advantages including: high operating autonomy, low operating costs per flight hour, complementary and on-ground data collection (on-site processing).

The proposed UAV LTA can use dedicated commercial sensors (TRL 6-7) or research phase (TRL 5) in versatile missions through intuitive C2 operation using open source or commercial tools

As drawbacks, we can point out: the high influence of unfavourable weather conditions on the LTA vector and the lower kinetics compared to the fixed wing UAV.

4. CONCLUSIONS

Aerostatic UAV are characterized by the use of reduced energy, provided by the lift aerostatic, but instead the energy is spent on displacement and compensation for wind disturbances.

Flight management in partially known dynamic environments is a complex issue. The flight route can be pre-planned taking into account current flight conditions and forecasts, but environmental changes must be made in the course of time. Even if predictive models can be improved, continuous weather changes and especially wind waves are very difficult to predict. Thus, the use of updates on in-flight weather information involves adjustments and re-planning based on current/short-term forecasts.

The weather forecast becomes an important component of the flight management system for detecting wind speed values, monitoring cloud development and motion, recognizing conditions for developing temperature inversions or local wind phenomena.

The benefits of environmental monitoring missions based on UAV-LTA must exceed the risks and be compatible with conventional ground-based methods. A balance between advantages and risks (security and safety) can be adjusted both by the existence and application of specific regulations and by increasing the quality of the human and technical factor.

For an air data acquisition process, sampling conditions determine both the flight characteristics and the performance of the sensors used to meet the mission objectives. Therefore, an adequate UAV usage is required based on the accuracy, scope and duration of the data acquisition, which can be optimized both in terms of resources and the confidence of the data taken.

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