THE DEVELOPMENT OF A SMALL-SCALE PPG-UAV FOR EMERGENCY RESPONSE ACTIONS

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In this paper is shown the development processes of an Unmanned Aerial Vehicle (UAV) that can be used for remote sensing, logistics or other emergency actions. The UAV is an ultralight aerial unit with an adaptable mission configuration. Thus, the configuration can be tailored to the type of intervention: observation, logistics, detection of certain personnel that are using Personnel Protective Equipment (PPE) equipped with radio ID transponders etc. The UAV is in fact a scaled down Powered Paraglider (PPG). The PPG-UAV uses a textile wing manufactured from a low weight double rip-stop nylon 6.6 fabric with extra coatings for air permeability reduction and added UV protection. The paraglider is linked with an Automated Command and Control (ATC) unit designed with increased modularity in mind allowing rapid reconfiguration based on the nature of the intervention. In this paper we summarize the fabric development followed by the paraglider pre-dimensioning, simulation using a numerical experimental model. The process is conducted on computer software developed within our institute. After the design phase the virtual prototype is preloaded for CNC cutting of the wing patterns, prototype assembly. The prototype is validated using computational algorithms combined with live testing in either static tests and/or simulated emergency live situations.

Keywords: Unmanned Aerial Vehicle (UAV), Powered Paraglider (PPG), Technical Textiles

INTRODUCTION

The objective of this project is to improve the service and operational response capacity for the National Emergency Situation Management System in Romania. In emergency situations all response structures act against the timer, and any means to reduce the response time can make the difference between life and death. Using the latest Unmanned Aerial Vehicles (UAV) technology, the response time can be reduced by allowing convenient remote sensing using many technologies like embedded-electronics, auto-pilot, high-capacity low weight batteries, materials that are strong yet lightweight, wireless communication, digital imaging, image processing software, positioning systems GPS, GNSS and so on. The value of an UAV for remote sensing, besides hardware and electronics, stay also in the software used that can automatically derive orthoimages by overlapping digital images and LiDar sensor point clouds. The fields of computer vision and deep learning AI can give a definitive advantage in remote sensing and data processing. Photogrammetric software supports can be embedded in UAV microcontroller and can control flight planning, calibration of cameras and triangulation for the creation of orthoimages such as 3D virtual landscapes in which a surveyor can interact with. For field survey high precision positioning data is required, and this is done by measuring through differential GPS, GNSS coordinates and corrected with internal inertial system data (Knache, 1992).

The specific objective of this project is to develop integrated support system in a way that is tailored for the specific operational requirements of emergency response actions. The system is composed of two components: protective equipment and support system for intervention actions. The support system is an Unmanned Aerial Vehicle (UAV) system that can be tailored to the nature of the intervention: disaster localization and monitoring, small scale logistics transport, detection of intervention staff using a

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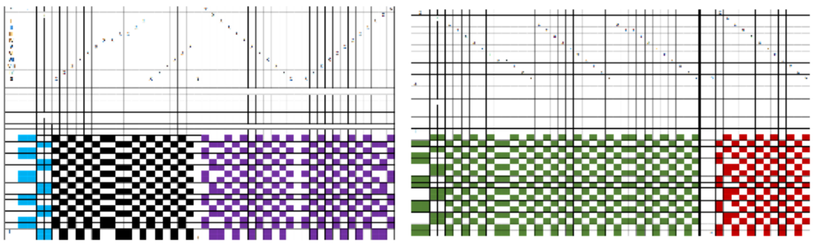
special Personal Protective Equipment (PPE) equipped with a special radio ID transponder, etc.

METHODS AND RESULTS

A comparative fabric design was done at the start of the projects. There were developed two fabrics using two woven types developed accordingly to the presented weave diagrams and characteristics (Cristian *et al*., 2012):

- Fiber composition of yarn: 100% PA6.6HT;
- Linear density of yarns: 30 den/32 f;
- Warp yarn count: 495 threads/10 cm;
- Weft yarn count for version 1: 504 threads/10 cm (fig. 1a);
- Weft yarn count for version 2: 508 threads/10 cm (fig.1b).



(a) (b)

Figure 1. Weave structure for version 1 (a. Ripstop) and version 2 (b. Double ripstop)

Several fabric variants were developed as follows:

- ripstop weave (F1 and F3) and
- double-ripstop weave (F2 and F4).

Each weave variant was also made in two finishing variants:

- calendering (F1 and F2) and
- polyurethane coating (F3 and F4).

Table 1. All variants fabrics test results

Test Name		Fabric F1	Fabric F2	Fabric F3	Fabric F4
Mass (g/m^2)		40	51	47	59
Yarn count	Warp	495	495	495	495
(threads/10cm)	Weft	504	508	504	508
Breaking strength	Warp	440	554	422	541
(N)	Weft	445	484	410	480
Elongation at	Warp	28.6	23.6	26.7	24.9
breaking force (%)	Weft	32.7	26.2	38.4	29.1
Tearing strength	Warp	34.4	21.3	65.2	20.7
(N)	Weft	32.7	22.5	65.5	20.7
Bursting strength (KPa)		330.3	368.4	330.2	370.8
Bursting strength (mm)		35.4	36.3	42.5	43.2
Air permeability (l/m^2/sec) at 200Pa		10.53	10.34	0	0

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Test Name	Fabric F1	Fabric F2	Fabric F3	Fabric F4
Raw material	100% PA66HT	100% PA66HT	100% PA66HT	100% PA66HT
Coating	Calendered	Calendered	PU coating	PU coating
Weave type	Ripstop	Double-ripstop	Ripstop	Double-ripstop

- Air permeability: the lowest air flow was on the coated ones (F3 and F4)
- Mass: lightest is the F1 variant.
- Breaking resistances: all variants show relative similar values but with slightly higher values with the double-ripstop variants F2 and F4. Increased tear strength is observed on the F3 variant, probably to the tearing mode which blocks the rupture propagation (Buyuk *et al*., 2019). This tearing behavior also exhibits on the F1 variant.
- Analyzing the test results we choose F3 as the working variant for the UAV textile structure prototype manufacturing due to the tearing behavior that presented the highest tear strength and can prove useful in maintaining canopy integrity.

The prototype manufacturing preparation starts at pre-dimensioning (Flores *et al*., 2014), this is done in a software program developed by the institute and this software includes a database (Fig. 2a, Fig. 2b) that stores a collection of materials commonly used in parachute manufacturing. The database contains the current stock of available materials that are to be used in the prototype manufacturing. The materials from the database can be selected manually or automatically by the software based on the technical parameters of the required material resulted from the calculation.

The methods used by the software for the pre-dimensioning are empirical and interpolation engineering methods commonly used in parachute design. On the virtual model more computational checks are computed using FEM methods for the parachute dynamic behavior in the deployment phase, flight attitude and landing.

Using the virtual model obtained after the pre-dimensioning phase, a drawing of the 3D model (Fig. 2c) is extracted. The 3D model undergoes a flow simulation and mechanical structural check for several phases of flight, starting at launch, stabilized flight, maneuvering flight and then landing. Maximum load estimation of forces on the canopy is done on launch/deployment phase, because at this moment the forces acting on the parachute constructive elements can exceed tens of times the forces encountered on stabilized flight, depending on the deployment altitude and speed. However, this is no longer valid for paragliders, because of the paraglider launching conditions, the forces acting on the canopy are quite low. Thus, in the case of paragliders in order to obtain the design forces, the simulation is made at the maximum load for a paraglider, namely at 80 km/h on a tight turn with 2-3 times the G-force acting on the canopy. During this phase in the design, we can calculate/estimate the fabric stretching and how it affects the wing aerodynamics. For the particular model developed in this project we are using NACA0012 airfoil for which we have precise measurements data done experimentally.

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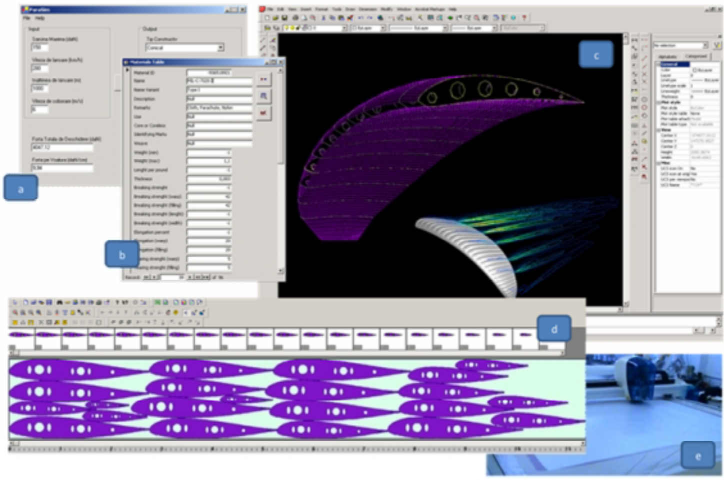

Figure 2. Computational workflow in parachute/paraglider design

Dimensional parameters can be modified if so desired after the simulation in done and checked for conformity (Ashby, 1999). 3D model resulted after this phase can be broken down into component parts and flatted down into patterns. The manufacturing markings are made on the fabric weft (Fig. 2d). The patterns are then sent to the cutting machine that performs fabric cutting (Fig. 2e). After this the parts are picked by an operator, marked and stitched according to the manufacturing process. The sewing is usually done with two needle seams on all structural parts.

Figure 3. Assembled main wing

Main Operational and Performance Requirements for the UAV Support System:

A1: Collecting information from where events occurred: fires, explosions, industrial accidents, floods, etc.;

A2: Detection of the NBC contamination level of an area;

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A3: Patrolling of some areas (border, communication routes, infrastructure - electrical networks, transport pipelines etc.) for the purpose of preventive detection of emergency situations.

On the basis of the collected data, it is possible to move to the second phase of efficient incidents management through:

B1: Persistent surveillance of the area where events occur that have a continuous spatial and temporal evolution (fires, floods, natural disasters, industrial accidents, etc.);

B2: Appropriate equipment for intervention staff with PPE tailored specifically to the event produced;

B3: Locating and tracking in real time intervention teams;

B4: Search for missing persons in natural environments covered with dense vegetation;

B5: Temporary provision of radio communication coverage of mobile radio communications networks in isolated / hard-to-reach areas or where terrestrial networks are unavailable / degraded;

B6: Small-scale logistics transport in remote areas.

The airframe that can host the payload according to the operational requirements consists mainly in the propellers shroud and the servo actuators supports and control arms for wing steering (Fig. 4).

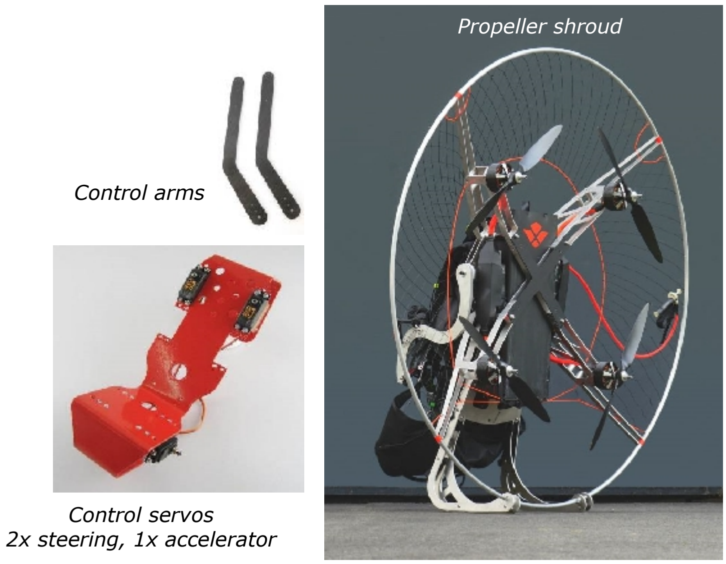

Figure 4. UAV airframe main components

The propulsion system consists in a quad propeller assembly where each propeller speed can be controlled independently. This assembly nullifies the propeller torque normally associated with single propeller assemblies and also gives extra steering and attitude control in addition to the wing controls.

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CONCLUSIONS

The resulted flexible ram-air wing is a PPG glider with a 6.8 m projected wing span.

The fabrics used in the manufacture of the wing have superior characteristics of weight and resistance. The fabric used is a double rip-stop nylon 6.6 fabric with urethane amino modified poly siloxane coating for UV protection.

The propulsion system is comprised of an electrical quad propellers system for increased manoeuvrability and portability.

The modular configuration of UAV support system and load variants implemented so far on the prototype are:

- Video suite: permanently mounted (for observation, monitoring, cartography and GIS);
- Sensor detection and localization sensor set: optional (for locating missing persons, fire detection and wind direction detection);
- Detection and localization of personnel that are using Personnel Protective Equipment (PPE) (Toma *et al*., 2018) equipped with radio ID transponders;
- Cargo unit: optional (for emergency transport of medicines and supplies in remote areas, small cargo, up to 10kg).

At the time of writing for this article we are undergoing live tests in order to assess the system performances, operational limits and identification of possible design/manufacturing flaws.

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