Design of a prototype fixed-wing drone for blood packet delivery applications

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Abstract—This paper proposes a fixed-wing drone design for blood packages delivery applications to solve the slow and inefficient transport system of blood units for transfusions in emergency operations in regions surrounding Lima, Peru. What is sought in this project is the structural stability of a drone to carry a maximum load of 5 kg, which will deliver parcels through an autonomously operated drop-down cabinet-box. The design consists of a series of sequential steps. First, the design of the wing assembly, which mainly involves the definition of the wing profiles; analysis of the forces and moments of the schematic composition of a fixed-wing drone; and location/measurements of the drone’s wing and tail. Second, the de-sign of the fuselage and cockpit-deployable box maintaining the location/measurements of the wing configuration. Finally, the static-dynamic structural analysis to evaluate the state of stress of the drone structures subjected to constant forces in the flight time. This evaluation looks for a configuration in which all the loads and forces of the mechanism are balanced.

Keywords—Drone, Fixed wings, Structural analysis, Delivery, CFD.

I. INTRODUCTION

The lack of blood units in the country is a constant problem, thousands of people die annually due to lack of access to blood units for transfusion [2]. Added to this, the culture of blood donation in the inhabitants is little or null; Most of the people who donate do so compulsorily, because someone they know requires units [1]. That is why we see ourselves in the need to have an efficient distribution system that allows us to beat the underlying problem and deliver units upon request.

Due to this, in recent years various solutions have been designed to attack this problem of global interest, especially for developing countries.

Zipline [3], an American start-up founded in 2014, noticed that there were similar problems in Rwanda and decided to make a fixed-wing drone delivery system between one of the collection centers and the hospitals where the medical units are destined; the package in that case is released by opening a gate in the fuselage that contains it.

On the other hand, in 2018, Stanislaw Bobela [4] presented a thesis on the development of a blood delivery system in India, with the difference that in this case the drones would be of the quadcopter type powered by four electric motors and having to the fastened package, not contained.

Finally, in 2019, Geoffrey Ling and Nicole Draghis [5] presented an investigation of the use of drones in the delivery of medical packages, performing a cost/time analysis and concluding that drones allow for improved response times and reduced delivery costs. Transportation.

Considering the observations raised by the research shown, what is proposed in this document is a delivery system for blood packages by means of a fixed-wing drone with a drop-down container box.

The design of a preliminary prototype of a transport drone using wings and tail with properly selected airfoil profiles, and a solid structure designed, will allow achieving the necessary stability and speed to transport an expected load through force and deformation analysis.

II. DESCRIPTION OF THE PROPOSED METHOD

The main objective of this document is to design a delivery drone and analyze in detail the structure so that it can fly at the required speed and support the expected load. The proposed method is described below.

![Fig. 1. Block diagram of the method.](image-url)

To do this, in the first place (A), the design of the wing assembly will be carried out, that is, mainly the shape, dimensions and angles in which both the wing and the tail are arranged with respect to the fuselage, once the wing profiles have already been chosen, in order for the set to present self-stability. The complete shape of the fuselage is not of primary interest because it does not affect this first analysis; however, the frontal area and the width of the profile are of importance to be able to perform calculations.

Secondly (B), a static-dynamic analysis of the forces that influence the different components of the drone will be conducted to ensure that it can withstand the flight conditions. For this, two factors will be analyzed: (i) the lift that is distributed along the wing and its reactions, as well as the thrust that pulls from the front and the drag that pulls back; (ii) air currents impacting the wing at the speed of flight. As for the rest of the structure, it is not included in this document...
because it does not have the same space restrictions and therefore it can have greater reinforcements to support the payload of up to 5kg.

A. Design of the wing and tail assembly

The choice of the wing profile represents an important decision that directly affects the design and characteristics of the drone, specifically the lift generated by the wings, but also the vertical and horizontal stabilizers located in the tail (T-shaped).

Among many profile standards the 4-digit family of the National Advisory Committee for Aeronautics (NACA) wing profile standard is used since it was the first series to be defined, being the best known and applied in different simulation software.

It is considered as NACA profile, those wing profiles that follow a standard and a specific nomenclature, which defines the geometric concept of the wing profile [6].

As shown in Fig. 2, two NACA profiles were chosen for the wing: 3412 and 4412. Because they have a similar behavior, except that the profile 4412 maintains stability at certain angles of attack slightly above the profile 3412. By placing a more stable profile at the ends, an anticipation of those angles of attack that can lead to instability without necessarily entering it is ensured in the aircraft.

Likewise, for the tail (stabilizers and rudder) a NACA 0012 profile was chosen, because symmetry is required; that is, it does not provide a bias for any of its sides (unlike the wing that is required to provide a bias for support), and this profile has good characteristics compared to other symmetrical profiles.

With the XLFR5 software, it can be obtained the behavior of the profiles regarding the lift coefficient (Cl), the drag coefficient (Cd) and the angle of attack (AoA) as shown below:

The 3412 and 4412 profiles have higher lift than the 0012 profile, because both are located at the wing while the third one is located at the tail. The lift to drag ratio has good lift behavior approximately between 3° to 10° of attack angles. So, considering a non-excessive angle with a good lift, an angle of attack (AoA) of 4° with a coefficient of lift (Cl) of 0.85 are defined as design parameters for this project.

With the wing profiles defined, the design needs to ensure that it has good behavior at the required speed and that it provides adequate support to be able to counteract the weight of the load. Therefore, in Fig. 6 an analysis of the forces and moments that schematically compose a fixed-wing drone is conducted.
With this, it is defined that the moment generated by the tail must be contrary to the wing, since it is necessary that they are counteracted to maintain stability in the system. Therefore, the resulting moment would be as follows:

\[ M = L_0 \times d - L \times D - M_0 \]  

(1)

Expanding and simplifying, one obtains in equation (2) a representation in coefficients of moments.

\[ C_m = \left( (d \times S') / (S \times \epsilon) \right) \times C'_L - D \times C_L - C_{m0} \]  

(2)

Where \( C_m \), \( C_{m0} \) are pitch and initial position wing moment coefficients; \( C'_L \), \( C'_L \) are wing and tail lift coefficients; \( S \), \( S' \) are wing and tail areas; \( D \), \( d \) are distances from the center of gravity to the aerodynamic center of the wing and tail; and \( \epsilon \) is the rope of the wing profile.

The equation (2) serves to identify which parameters must be modified in the design to achieve stability. For modifications, it is important that they meet the following requirements: 10kg of lift (including payload), 100km/h of cruising speed. In this way, the minimum area of the wings can be calculated with equation (3)

\[ L = \left( \frac{1}{2} \right) \times \rho \times S \times C_L \times V^2 \]  

(3)

Where \( L \) is the lift [N]; \( \rho \) air density [kg/m3]; \( S \) the wing area [m2]; \( C_L \) the lift coefficient; \( V \) the velocity [m/s]. Replacing with the already obtained values, \( S \) would have to be greater or equal to 23m².

In that sense, with the XLFR5 software, an analysis of the coefficient of moment (\( C_m \)) is carried out with the angle of attack (AoA) since the behavior that the aircraft will have in the face of a disturbance at cruising speed of 30m/s can be determined.

Different iterations of configurations can be observed in the image, by modifying the variables mentioned in equation (2) to obtain the ideal configuration for self-stability. So, as defined an angle of attack of 4° in Fig. 4 and 5, option 5 (cyan line) is chosen. In such way, the wing configuration is as follows:

To carry out the structural design of the fixed wing drone it is necessary to know all the measures for implementation. For this, the Autodesk Inventor software is available where the final design of the drone is made. It is also important to define an adequate structure, since this affects the resistance and performance of the drone, as well as the payload that it will be able to carry, where greater weight less load and vice versa.

This study will focus on the structure of the wing. It is planned to be used as materials for the drone, wood, and polystyrene as body-filler. With Autodesk Inventor software, it is created the next structure:
This section of the wing is the one that mainly exerts the lift, so it must be resistant. Added 10 balsa wooden ribs that are joined through 3 rods and 1/2 rod of radiata pine wood with the same diameters of the central wing. In the part of the 1/2 rod is coupled to a rectangular rod of the same material, which serves as a union with the wing ailerons, this union will be made with small acrylic hinges.

In section B, a stress analysis is carried out to determine the stress and deformations that can be generated in the structures. In addition, the entire drone prototype is designed as follows:

\[ L_d(x) = \sqrt{1 - (2x/0.702)^2} \] (4)

As mentioned above, the lift is not a punctual force, but is distributed along the wing, represented with green arrows in Fig. 15 and follows an approximate behavior to equation (4). In addition, we have the force of weight and thrust, which are punctual forces and concentrated in the union with the fuselage (parasitic drag forces also affect here, but they are insignificant compared to the weight) and in the fastenings of each engine, respectively. The latter is found approximately at the centroid of the graph describing the distribution of forces approximately 258.6 mm from the root of the wing root according to equation (5).

\[ \bar{x} = \frac{\int_{x_{min}}^{x_{max}} dA \times x}{A} \] (5)

Where \( dA \) is \( L_d(x) \) by \( dx \) and \( A \) is the area below the described curve.

Below are the following graphs: Fig. 16 of shear forces on the wing \( V(N) \); Fig. 17 of flexing moments on the wing. Both graphs are also described in equations (6) and (7), \( \bar{L} \) being the lift that gives each side of the wing, in this case 125, and \( M_{en} \) the weight of the engine, in this case 1.78N.

\[ V(m) = \begin{cases} \int L_d(x)dx, & -0.702 \leq x < -0.12 \\ (L - M_{en})/3, & -0.12 \leq x < 0 \\ (M_{en} - L)/3, & 0 \leq x < 0.12 \\ \int L_d(x)dx, & 0.12 \leq x < 0.702 \end{cases} \] (6)
As can be seen in both images, the critical points are the joints between the wing and the fuselage located at the ends and center of the fuselage, in all these there are cutting forces of great magnitude. However, the most critical part is to the center, which also supports the maximum flexing moment with about 37Nm, so it must have the greatest reinforcement.

On the other hand, paying attention to the wing itself, in Fig. 18 the aforementioned forces do generate a certain deformation in the wing, tolerable but considerable, especially taking into account that it implies forces of great magnitude.

As can be seen in the images shown, due to the wind column generated, the wing is mostly unaffected: its deformation is negligible, compared to the dimensions of the structure and the stress it supports in general has very low values. Although in the latter case, it is appreciated that the joints have the greatest stress, they do not become values of great magnitude that can have a considerable negative impact on the drone.

### III. RESULTS

#### A. Drone Stability Analysis

For stability, as obtained in Fig. 7, it is set for an angle of attack of 4°. It should be noted that this value refers to the inclination as a whole (wing, fuselage, tail, etc.). Otherwise, as shown in Table I, it is the individual base inclination with respect to a set tilt angle of 0° (starting position of the drone).

<table>
<thead>
<tr>
<th>Main Configuration</th>
<th>Wing</th>
<th>Elevator</th>
<th>Rudder</th>
</tr>
</thead>
<tbody>
<tr>
<td>NACA</td>
<td>3412, 4412</td>
<td>0012</td>
<td>0012</td>
</tr>
<tr>
<td>S (m²)</td>
<td>0.32</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>AoA(°)</td>
<td>2</td>
<td>-3.5</td>
<td>N.P</td>
</tr>
</tbody>
</table>

*Angle of attack  
*Does not present

In this way, with the wing configuration defined, a stability simulation is carried out in the Xflr5 software against different angles of attack (AoA) as shown below:
It is observed that for an angle of attack less than and greater than 4°, the generated moments maintain an opposite direction in order to generate a self-inclination towards the stable value.

B. Structural Analysis of the Drone

What can be seen in Table II is that for the static analysis carried out in Inventor, there are considerably high values for both deformation and Von Mise stress. When interpreting these, it should be borne in mind that the analyses have been carried out with loads greater than those that the drone will be affected; under normal conditions, with a load of 100N, the maximum deformation would be 18.12mm, while the Von Mises stress would be only 122.8MPa in just one section of the supports.

### Table II

<table>
<thead>
<tr>
<th>Analysis Table</th>
<th>Static (Inventor)</th>
<th>Dynamic (Ansys)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformation (mm)</td>
<td>0</td>
<td>45.29</td>
</tr>
<tr>
<td>VM Stress (MPa)</td>
<td>0</td>
<td>307.1</td>
</tr>
</tbody>
</table>

*Von Mises Stress

IV. CONCLUSIONS

It was concluded that the definition and selection of a NACA wing profile guarantees a functional design and excellent results. This process is a priority since, seen in flight theory, the wing profile generates the lifting forces.

The use of Xflr5 software was of crucial importance for the development of a preliminary prototype, to be able to perform analyses and define mechanical design parameters. Likewise, other simulation and design software guarantee the solidity of the structure when subjected to the normal efforts of the drone's tasks.

In the design of the drone, for cruising speed, the presence of self-stability is important. Which was defined, for this study, in an angle of attack of 4°. This parameter validates that the drone in the face of different planned and unforeseen disturbances self-stabilizes without the need for a control system and/or human intervention.

It is observed that even exposing the model to great efforts, simulating extreme situations where the support in theory doubles the weight, the design responds with a certain tolerance and allows to maintain the solid structure.

For a speed of 30m/s, chosen for design, the model is not only stable but also presents tiny deformation and stress values, imperceptible for any effect.

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