Title:
Geometric Analysis of the Proportion and Movement of the Wings of the Bee, the Mosquito and the Butterfly

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Introduction:

In this work, we present the research carried out at the Autonomous Metropolitan University Campus Cuajimalpa in México City, whose objective is to study different types of insects to find out if there is a relationship between their wings. In this project, we work with the bee that belongs to the *Apidae* family. With the mosquito that belongs to the *Culicidae* family and with a butterfly of the family *Nymphalidae*.

We find, using the geometric Morphometrics technique [3], the numerical values of the "X" and "Y" coordinates of the points in space and we model the solid [2]. We built three prototypes in 3D printing, and made three virtual models and three simulations to perform the stress analysis and wings movements respectively. For the physical prototypes, a 4 mm thick ABS plastic was used, and a hook-shaped stainless steel wire with of 2 mm of diameter was placed in the center of the heavier parts of each of the wings as an axis. In addition, in the virtual models and, to perform the simulations of the wing movements three proposals were made to perform the stress analysis and the simulations respectively: (1) the wing without structure, (2) the wing with a straight structure and (3) the wing with the hook structure.

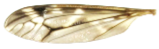
From the research carried out, the hypothesis of our project arises: the simulations of the movements of the wing of the insects differ if an axis passes through the center of the heavier parts of the wing.

We concluded in our study, that the factors that influenced the least displacement and deformation of the wings in the simulation of the wing movements of the insects studied are the hook-shaped structure plus the shape, the weight, location and length of the veins and centroid of the wings.

Main Sections:

The wings of the insects are composed of two cuticle membranes pressed and supported by a series of venation. The terminology of the wing venation of insects is important for the classification of almost all taxa of insects. A complex nomenclature is used from one group to another but is generally based on the Comstock-Needham system (1898) [1].

In the insects studied, the shape, length and width of the wings and their venation are very different (Tab. 1) as well as their weight.

	Real size				Scaled			
	Bee	Mosquito	Butterfly			Bee	Mosquito	Butterfly
Long	8.66	19.9	40.23		Long	190.52	199	201.15
Width	2.32	5.02	19.2		Width	51.04	50.2	96
					Scale value	10	22	5

Tab. 1: Length and width in mm of the insects studied given in mm.

<u>Analysis of the proportions:</u>
A photograph of the bee wing was taken and we open the JPG file in a graphics program (Photoshop); the points and lines were marked to delimit the contour of the shape of the wing and the location of the nerves (Fig.1(a)). The wing was adjusted to its real size (Tab.1) modeled with a height of 0.06 mm plus 0.0 1mm in height of the nerves both in the upper part and in the posterior part, and with a thickness of 0.02 mm. (Fig.1(b)). The centroid of the wing was found, two axes were traced, one transversal and the other longitudinal, and two cutting planes were placed. (Fig.1(c)). The wing was cut into four parts (Fig.1(d)).

The centroid of each of the resulting parts were marked and four axes were traced, two transversal and two longitudinal passing through the centers of each of the parts reaching the wing contour. Four cutting planes were placed (Fig.1(e)) and the wing was cut into 16 parts (Fig.1(f)). This same procedure was carried out with the butterfly and with the mosquito.

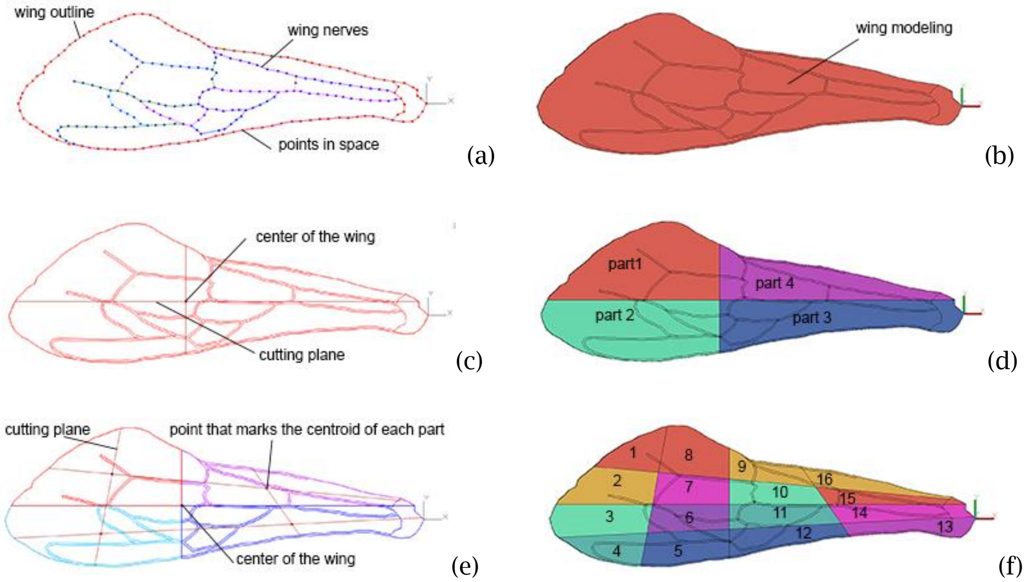


Fig. 1: Bee wing (a) Points in space, outline and nerves lines, (b) Modeling, (c) Center and two cutting planes, (d) Four parts, (e) Center and six cutting planes, and (f) Sixteen parts.

To find the weight of the wings, a plastic ABS was used with an elastic limit of 2900.75psi and, with a density of 1.38 g/cm³. The results obtained were the following.

- The weight of each of the four parts of each insect studied (Tab.2).

	Part 1	Part 2	Part 3	Part 4	Total weight
Bee	0.37	0.38	0.36	0.27	1.38
Mosquito	0.13	0.19	0.18	0.16	0
Butterfly	13.60	10.69	12.49	10.03	46.81

Tab. 2: Weight of each of the four parts of each insect studied given in grams.

- The weight of each of the 16 parts of each insect studied (Tab 3).

	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8
Bee	0.07	0.11	0.11	0.07	0.11	0.08	0.08	0.11
Mosquito	0.51	0.86	0.68	0.5	0.70	0.58	0.63	0.84
Butterfly	2.68	4.00	3.26	1.72	3.18	2.52	2.88	4.02
	Part 9	Part 10	Part 11	Part 12	Part 13	Part 14	Part 15	Part 16
Bee	0.07	0.08	0.09	0.10	0.08	0.09	0.06	0.06
Mosquito	0.55	0.56	0.66	0.84	0.67	0.72	0.57	0.47
Butterfly	2.92	2.48	2.85	3.89	1.89	3.87	2.83	1.80

Tab. 3: Weight of each of the 16 parts of each insect studied given in grams.

It can be observed in Table 3 that the parts 2, 3, 5, 8, 12 and 14 are the heavier parts of all the wings, so we conclude that the heavier parts of the wings are located in the same sections.

We made several tests to join the centers of each of the six parts of greater weight of the wings of each of the insects. At the beginning, we saw that we had different paths in each of the wings if we followed the order of the weights. We also observe that if the order of the nomenclature is followed, the resulting path would have many curves, which would cause problems when bending the internal structure that is intended to be placed; the path would cross through the lighter parts of the wing and, more weight would be added to the wings. Therefore, we conclude that if we follow points 8, 2, 3, 5, 12 and 14, the path that would give us in all the wings will be a hook (Fig.2).

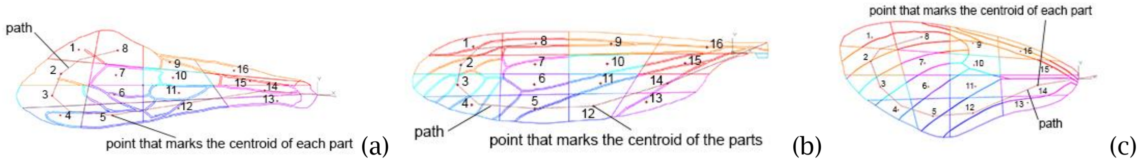


Fig. 2: Hook path (a) Bee, (b) Mosquito and (c) Butterfly.

<u>3D bee prototype:</u>

For the 3D prototypes, the wings were scaled to the maximum length that allows us to print the 3D printer (200 mm), with a height of 4 mm. What determined this height was the canal size of 2.08 mm high by 2.08 mm wide, to place the stainless steel wire of 2 mm in diameter plus the tolerance and the minimum distance that the 3D printer allows us to cover the entire surface. The nerves were modeled with a height of 1 mm both in the upper part and in the back part of the wing, and with a thickness of 0.7 mm.

To make the prototypes, the wing of the bee was divided into two parts; a canal of 1.04 mm high and 2.08 mm width was opened on each side following the path (Fig.3(a)). The prototype in 3D printer was build, the stainless steel wire was placed (Fig.3(b)) and, cyanoacrylate was used to glue each one of the wings. Finally, the wings were placed on a base (Fig.3(c and d)). The same procedure was performed on the other wings.

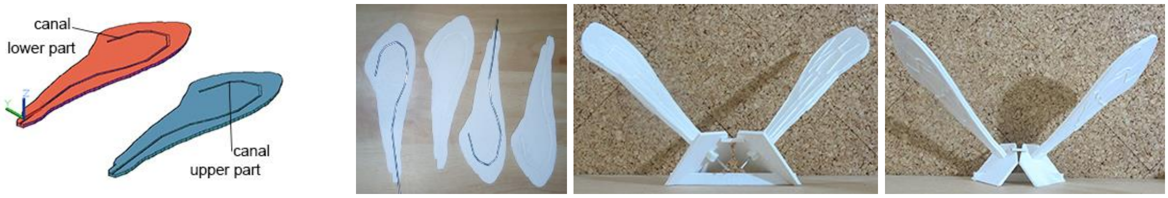


Fig. 3: Bee wing (a) Canal, (b) 3D printing with the wire and (c and d) On a base.

The purpose of making the prototypes was to observe and analyze the behavior of the wing when we hold the structure and we made with our arm three movements: from front to back, top to bottom and circular (Fig.4). The results we obtained were interesting, since first when we moved our arm from front to back, the wing moved freely, did not turn and returned to the starting position. In addition, when we moved our arm making circles, raising, and lowering it, the wing always kept its balance and moved freely following the path of our arm.

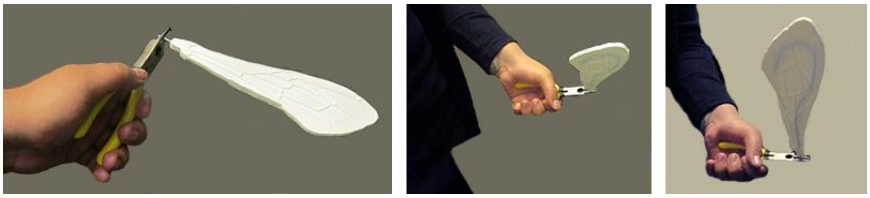


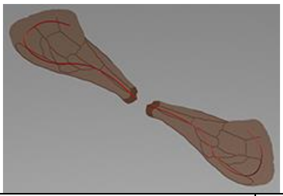
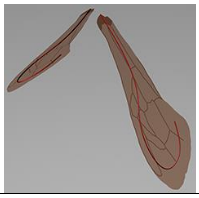
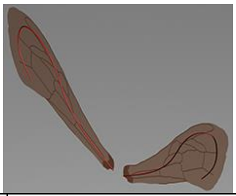
Fig. 4: Behavior of the wing when we hold the structure.

<u>Virtual model stress analysis:</u>
In this study, the simulations were carried out in the Inventor program. An ABS plastic was used on the scaled wings, with an elastic limit of 2900.75 psi and a density of 1.38 g/cm³. In addition, stainless steel with a density of 7.75g/cm³ was used for the structure. Three tests were performed on each of the wings studied with a force of 1lb: (1) the wing without structure, (2) the wing with a straight structure and (3) the wing with the hook structure. In the displacement of the wings, the results are given in inches, and are the following: (a) without structure: bee 0.61, mosquito 1.26 and butterfly 0.47, (b) with straight structure: bee 0.21, mosquito 0.51 and butterfly 0.14 and (c) with hook structure: bee 0.16, mosquito 0.12 and butterfly 0.08.

The results show that the structure in the form of hook has the least displacement mostly in the mosquito. Using this structure, we proceed to make the 3D animations of the movements of the wings to check our hypothesis.

<u>3D animation of the wings movement:</u>
The simulation of the movements of the wings was done in the 3D Studio Max program. Two types of movements were made: the rotation movement on the "X" axis and the translation movements on the "Y" axis in each of the wings of the insects studied.

Twenty-two turns were applied for every five squares of 105 in total of each wing (left and right). In all the wings of the studied insects, its corresponding path with the hook form was used. As an example we show the movements of the bee (Tab. 4) in frames 0, 10, 20 and 25. The numerical values that were used to perform the rotation movements and, the translation movements are given in degrees.

			
X= -45 Y= 0	X= 0 Y= -50	X= 95 Y=35	X= 0 Y= 50

Tab. 4: Movement of the bee wings.

In 3D animation, we realize that the wings of the studied insects remain stable, using the hook-shaped structure before and after performing the movements of both rotation and translation. This is because the hook-shaped structure passing through the heavier parts helped the wings have resistance to the gravity (Fig.5).

Fig. 5: Wings movements (a) Bee, (b) Butterfly and (c) Mosquito.

Contribution:
The paper we present contributes to scientific research since we find, from the morphological point of view, the true shape and magnitude of the wing and the location of its nerves. From the geometric point of view, we find that there is a relationship in the parts of heavier weight of the wings of the insects no matter their shape and size. In addition, from the point of view of 3D animation, it is suggested to place a wire with the form of a hook as an axis since the hook does not allow the wing to have too much displacement and deformation, aspects that are not taken into account in the simulations.

Conclusions:
We conclude that the hypothesis that we set out was verified: the simulations of the movements of the wings of the insects differ if the axis passes through the center of the parts of greater weight of the wing.

References:

[1] Comstock, J. H.; Needham, J. G.: The wings of insects: The American Naturalist, The University of Chicago Press https://www.jstor.org/stable/pdf/2452973.pdf

[2] Rochman, D.: Prototyping the complex biological form of the beetle Deltochilum Lobipes via 2D geometric morphometrics landmarks and descriptive geometry for 3D printing, Computer-Aided Design & Applications, 14(1), 2017, 107-116. https://doi.org/10.1080/16864360.2016.1199761

[3] Zelditch, M.; Swiderski, D. L.; Sheets, H. D.; Fink, W.: Geometric Morphometrics for Biologist: A Primer, Elsevier Academic Press, USA, 2004.