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A Study of the Relationships between Pressure and Deformation of Surface on Wingsuit Performance

M. Nazemian Alaei, M. S. Valipour*

Department of Mechanical Engineering, Semnan University, Semnan, Iran

ABSTRACT: Wingsuit as one of the most popular sports in the field of aviation is very popular. Efficiency and safety are the first priority of the designers of this sport. In this article, the modeling, formation, and evaluation of the surface of the wingsuit during a flight are discussed. Since the wingsuit is under air pressure inside it, the formation of the structure of the surface of the suit changes according to the flight conditions. The surface of the wingsuit is important for the aerodynamic evaluation of the wingsuit model. According to the way of sewing wingsuit clothes, the wave structure will be obtained on the surface of the wing. In order to better observe the effects of changing the wing geometry on maneuverability, the model has been selected as rigid. The experimental results on the surface of the model show that with the increase of the angle of attack, the flow on the surface of the wing increases the disturbance in the middle area of the wing and reduces its effects in the upper area of the wing. This interaction of the flow structure on the model leads to the different performances of the model in different angles of attack; By measuring the forces on the model, AOA= 15◦ was obtained as the best angle of flight performance for the wingsuit model.

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1- Introduction

Wingsuits with flexible wings with unique advantages such as lightness, quick response, and low cost of these types of wings have become a significant focus among aviation professionals around the world [1]. Lafayette et al. [2] conducted a comprehensive study on wings with wave-shaped surfaces on air drones; They successfully tested the structural and aerodynamic advantages of air pressure-inflated wings compared to rigid wings. Jia et al. [3] investigated the wing surface geometry in the inflated state to evaluate the aerodynamic characteristics of the angle of attack at high angles for takeoff and landing. In fact, the flexible wing has an elastic appearance deformation under the changing pressure, and the deformation on the surface of these types of wings has a direct effect on the flow structure, also this type of structure will have a significant effect on the bearing of the wing. The stress level and the method of improving the modulus of elastic deformation of the membrane, and wing to maintain the shape and stiffness have been investigated in recent years. Studies of flexible wings have been done mostly around drones, therefore, according to the results obtained from previous studies, the investigation of limited flexible wing geometry on wingsuits has rarely been done.

2- Modeling of Wingsuit Wing Surface

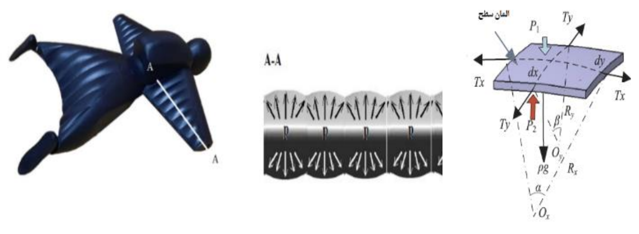
By observing the wavy arrangement created by the way of sewing in the wingsuit, the surface of the wing is formed; The reason for sewing clothes with this shape is to increase the strength and efficiency of the wing during flight. The calculations have been made assuming that these waves are evenly distributed on the surface of the clothes. For calculation and modeling, the dynamic state of the clothing (general shape of the clothing during flight) has been used. (Fig. 1(a))

According to the assumption of the problem, the amount of air entering and leaving the shell is insignificant, so the air pressure p is maintained inside the shell, in this case, a convex shape is obtained for the outer wall. Assuming that the Wave scale and amplitude of them were the same in the transverse direction of the suit, the mathematical modeling for the surface is presented as follows.

$$f\left(y, h_m, y'_0\right) = \frac{y}{h_m} + \exp\left[-1.5\left(y'_0\right)^2\right]\left(1 - \frac{y}{h_m}\right) \qquad (1)$$

In this study, stress modeling has been done when the wing is inflated. The wing skin surface element is considered in 3D deformation mode, however, in this structure, the wing surface can be freely contracted and stretched. Therefore, the local deformation leads to the tensile deformation in

*Corresponding author's email: msvalipour@semnan.ac.ir



(a) (b)

Fig. 1. pressure distribution inside of a wingsuit

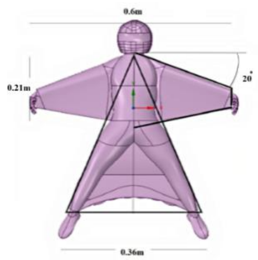


Fig. 2. The geometry of the wingsuit mode

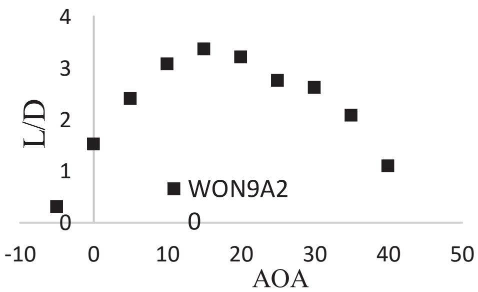


Fig. 3. Performance diagram (L/D) at Re= 1.5×10^6

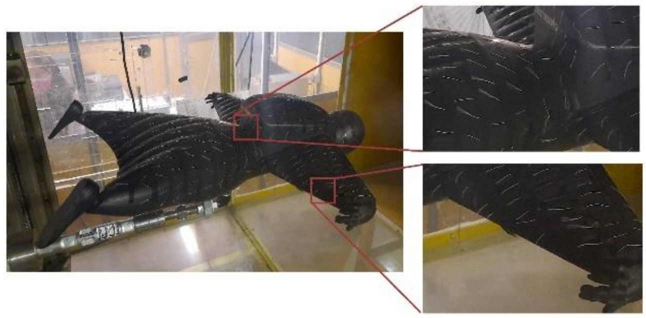


Fig. 4. Tuft flow visualization at AOA=15◦

two axes of the wing surface, therefore, when performing the local stress analysis of the wing surface, only one local unit (element) should be selected for modeling the wing. The small element is selected from the rectangular surface as shown in (Fig. 1(b)).

T is the tensile force of the fabric per unit length of the piece and the vector $p=(p_x,p_y)$ is equal to the air pressure in the shell, which is at any point of the shell along the normal. By defining the element ds of the convex length of the wave (L_W), we have:

$$T(x)=\frac{\rho a v^2\left[1+0.5\left(y'\right)2\right]}{2\left|y''\right|} \quad (2)$$

$$T(y)=\frac{3\rho_a v^2(1-\ln f)\left[y+\exp\left(-1.5\left(y'_0\right)^2\right)\right](h_m-y)}{2\left[1-\exp\left(-1.5\left(y'_0\right)^2\right)\right]} \quad (3)$$

Generally, the flexible wing material is reinforced with laminated anisotropic composite fibers. The different effects of elasticity modulus should be considered in the x and y directions respectively. Axial elastic moduli are expressed as E_x and E_y. Also, the relationship between the stresses introduced in the two axes for the flexible surface in the two x and y axes respectively as σ_x and σ_y, taking into account the requirements in the above relations, are generally defined as follows:

$$\sigma_{(x,y)}=\frac{\left(\frac{m_{gas}R_{gas}T_{environment}}{M_{gas}V_{gas}}-P_1-\rho g\right)}{\left(k_{(y,x)}\cdot\frac{E_{(y,x)}T}{E_{(x,y)}T}\cdot\frac{K_{(y,x)}+\mu K_{(x,y)}}{K_{(x,y)}+\mu K_{(y,x)}}+K_{(x,y)}\right)t} \quad (4)$$

The dimensional size of the test model's length is determined according to the dimensions of the test room and the obstruction ratio in the test room according to the standard of the wingsuit manufacturer of the training brigade model. The geometry and dimensions of the wingsuit model based on the anthropometry of the adult male body are shown in Fig. 2. The dimensional size of the length of the model to be tested is determined according to the dimensions of the test room and the ratio of obstruction in the test room. The blocking ratio of the model is 4.1% at the zero angles of attack and 10.4% at the angle of 35°, which should not be more than 15% at the maximum angle of attack of the model.

The base model of the wingsuit the dimensions of 0.36, and the actual sample with the dimensions of 0.7m is made with the WON9A20 wing model in the hand section with the angle of attack edge retreat of 20° and also the aspect ratio of 2.22. The wingspan of the model is 0.6 meters, and the chord of the wing root is 0.21 meters. The laboratory model used is shown in Fig. 2.

3- Results and Discussion

3- 1- Balance measurement

Aerodynamic force coefficients were measured by an external balance for the wingsuit model. Fig. 3 shows the drag and lift coefficient diagrams as well as the performance diagram of the wingsuit model with wavy wings at the Reynolds number of 1.5×10^6. From the performance graph, it can be concluded that the WON9A20 model performs better at attack angles of 10° to 20° than at high attack angles, as it can be seen that the efficiency of the wingsuit model reaches its maximum value at an angle of 15°.

3- 2- Flow structure with mini tuft visualization

The flow pattern in the back and side view of the wingsuit model at the angle of attack before stalling with the wing with a wave structure at $AOA=15^\circ$ are shown in Fig. 4, respectively. As can be seen, in this model, the vortices move from the trailing edge of the wing to the leading edge and cause flow disturbance at a distance of $x/c=0.35$ from the leading edge of the wavy wing. This vortex formation leads to an increase in the drag coefficient.

4- Conclusion

Flexible wings have been given a lot of attention due to their lightness and low cost in the construction of flying devices. Generally, these types of wings are considered wave-shaped wings. The performance chart shows the highest flight performance for this type of wingsuit at $AOA= 15^\circ$. By analyzing the vortices caused by the surface and the edges of the wing by visualization on the model, it is observed that in different angles, the way flow lines are messed up and the vortices grow on the surface is different.

References

[1] M. Abrams, Birdmen, batmen, and skyflyers Wingsuits and the pioneers who flew in them, fell in them, and perfected them, Broadway Books, (2007).

[2] D. Takahashi, R. LeBeau, Computational investigation of flow over inflatable airfoils at multiple reynolds numbers, in: 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, (2011) 377.

[3] L.B. Liu, Y.C. Jia, Y. Wei, Structural design and mechanical deformation simulation of flexible inflatable wing for miniature missile,J Natl Univ Defense Technol, 40 (6) (2018) 30-37.

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