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Wind Tunnel Testing of a Novel Wingsuit Design

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Abstract

A wingsuit is a special suit that is worn to allow the user to fly after jumping off of a high cliff. The wingsuit creates an airfoil shape by adding wings of material between the arms and the sides as well as a tail consisting of material between the legs. The wingsuit allows for the creation of lift and thus human flying. A new and novel wingsuit design is proposed based on the design of a delta wing aircraft. This new wingsuit has material leading from the side of the head and connecting to the top of the arms, extending the area of the forward wing. Using a mannequin in a wind tunnel, the aerodynamic performance of the new wingsuit will be measured and compared to that of the current wingsuit design. The results show that the redesigned wingsuit had a lower lift-to-drag ratio in most testing scenarios. The decrease in lift-to-drag ratio was due to the combination of an increased lift and a higher increased drag.

Keywords: wingsuit; aerodynamics

1. Introduction

Wingsuits are the next step in unpowered, manned flying. Wingsuits are outfits that are worn by the wingsuit pilot and alter his/her body shape in order to allow it to glide. Pilots can jump either from cliffs or out of an airplane into a steady glide, which terminates when the aviator opens his or her parachute. While flying and landing in a wingsuit is not currently feasible, companies and pilots report glide ratios to be about 2.5 in optimal conditions [1]. The glide ratio is the ratio between the lift force and drag force; each of these three parameters is important to wingsuit pilots. In general, for long-range flight a high glide ratio is desired, for increasing fall time, a higher lift force is desired, and increasing forward speed requires a reduction in drag force. Wingsuit pilots are interested in the wingsuit's glide ratio, maneuverability, and stability.

To date, little research has been done on optimizing wingsuit lift and drag properties. Most wingsuit companies follow a "re-sew, jump, observe" methodology to increase wingsuit performance. Hence a wingsuit designed with the goal of increasing the lift-to-drag ratio using aerodynamics and wind tunnel testing could be of great value to the wingsuit community.

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2. Experimental Overview

During this experiment we redesigned a typical wingsuit, the Phantom 2 wingsuit (Phoenix-Fly; Strmec, Croatia) with the goal of increasing the lift-to-drag ratio of the wingsuit. Both the original and redesigned wingsuits were tested in the Massachusetts Institute of Technology Wright Brothers Wind Tunnel under typical flight conditions. The experimental apparatus consisted of four parts: the original wingsuit, the redesigned wingsuit, the mannequin on which the wingsuits were placed, and the mount on which the mannequin was placed. The lift and drag generated at varying wind speeds and angles of attack typical of wingsuit flight were measured. The glide ratio was calculated from the recorded data.

3. Wingsuit Design

The goal of the revised wingsuit design was to develop a wingsuit with an aspect ratio (AR) of two. The aspect ratio is defined as the wingspan squared divided by the wing area. The original wingsuit has an aspect ratio of 1.5 and an estimated glide ratio of 2.5[1]. Initial calculations were done on the drag force generated by the original wingsuit to see how the drag was distributed between induced drag and profile drag. Induced drag is the drag caused by the generation of lift and the profile drag is the drag due to the shape of the object. The lift coefficient, C_l was estimated using thin airfoil theory [2]. Using the glide ratio of 2.5 provided by Phoenix-Fly, the drag coefficient, C_d, was estimated as

$$C_d = C_l\left(\frac{L}{D}\right)C_d, \tag{1}$$

the induced drag coefficient, C_{d_i}, was calculated using

$$C_{d_i} = \frac{C_l^2}{\pi\, AR}, \tag{2}$$

and the profile drag coefficient, C_{d_p}, was then calculated using

$$C_{d_p} = C_d - C_{d_i}. \tag{3}$$

The calculations showed that the drag of the original wingsuit consisted of 74% profile drag and 26% induced drag. Increasing the aspect ratio of the wing will reduce the induced drag. Reducing the apparent cross-section and improving the streamlining of the wingsuit will reduce the profile drag. Reducing drag by 15% means that the glide ratio would be 3; this could be achieved by increasing the aspect ratio to 2.

A wingsuit is composed of two wings: the upper wing consists of the wings between the arms, and the pilot's upper body, and the lower wing consists of the wing between the legs and the pilot's legs. The lower wing's aspect ratio cannot be increased due to the pilot's inability to abduct his/her legs laterally beyond their natural range of motion and hold them in that position for long periods of time. Hence, the redesigned wingsuit's upper wing is redesigned by adding an additional forward wing resulting in an aspect ratio of 2.75 for the combination forward and upper wings and an aspect ratio of 2.0 for the entire wingsuit. As shown in Figure 1, the redesigned wingsuit's new forward wings were added above the arms up to the side of the pilot's head. No modifications were made to the lower wing of the redesigned wingsuit.

Fig 1. Redesigned Wingsuit. [3].

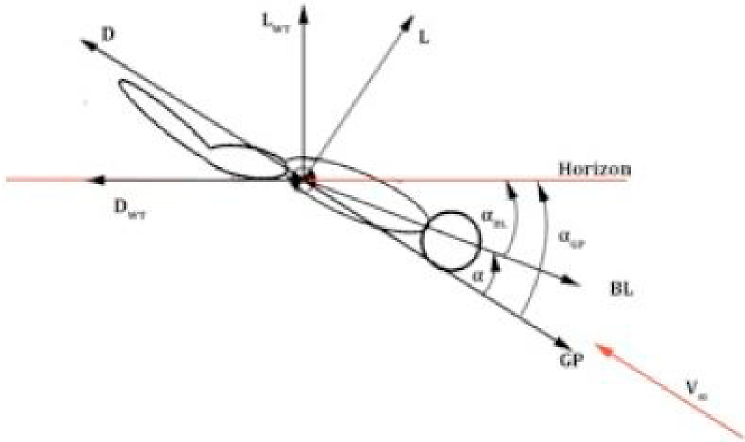

Fig 2. Wingsuit Flight and Angle of Attack.

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4. Wingsuit Flight Parameters

Wingsuits are flown along varying flight paths, during which pilots often curve, bank, and dip. For simplicity we will consider the case where the wingsuit pilot is in a stable position and not manipulating the characteristics of the wingsuit by moving his/her arms or legs. As shown in Figure 2, we have defined the pilot's glide path (GP) to be parallel to the free-stream velocity (V_∞). The angle from the GP to the horizon is labeled as α_{GP}. We calculated α_{GP} = 22° which corresponds to a flight path with a glide ratio of 2.5. The bodyline (BL) is the line along the pilot's body and α_{BL} is the angle from the bodyline to the horizon. The angle of attack (α) is equal to $\alpha = \alpha_{GP} - \alpha_{BL}$.

Figure 2 shows the body in flight, and the forces in the wind tunnel coordinate system and the free-stream coordinate system. The lift force (L) experienced by the pilot is defined as orthogonal to his glide path, while the drag force (D) is defined as parallel to his glide path. L_{WT} and D_{WT} correspond to the lift and drag components as reported by the wind tunnel force balance. These are defined as orthogonal and parallel to the horizon, respectively. The glide path and horizon are not necessarily the same. Therefore, L_{WT} and D_{WT} need to be converted to L and D. L and D were calculated using the following relationships:

$$L = \cos(\alpha_{GP})L_{WT} + \sin(\alpha_{GP})D_{WT} \text{, and} \tag{4}$$

$$D = \cos(\alpha_{GP})D_{WT} - \sin(\alpha_{GP})L_{WT} \text{ .} \tag{5}$$

5. Methods

The wingsuits were manufactured to fit a mannequin that was approximately 1.75 m with an athletic build (Palay Display, Bloomington, MN, USA). The mannequin had a flexible steel core with a foam surrounding. This allowed the mannequin to be positioned in a typical flight position, but it needed rigidity to prevent it from folding during testing at high speeds. This rigidity came from a mount that consisted of aluminum plates strapped to the mannequin's front and back, as well as aluminum bars restraining the arms. This assembly was connected to the wind tunnel balance through a center post underneath the mannequin's abdominal region.

Wind tunnel testing was completed at angles of attack of 0° to 25° in 5° increments. This range corresponds to a range of conditions from where the pilot is flying directly into the free-stream, to where the pilot's body is at an angle of 3° above the horizon (α_{BL}). The wingsuits were tested at wind tunnel speeds varying from approximately 22 m/s to 31 m/s in 4.5 m/s increments and from 31 m/s to 40 m/s in 2.25 m/s increments. For each test case, approximately 200,000 data points were collected and averaged.

6. Results

The results from the wind tunnel tests are shown in Figure 3. The ratio of lift to drag is plotted as a function of wind speed. Each plot is for a given angle of attack. The data for the redesigned wingsuit is shown in the dashed lines with O's, the data from the original wingsuit is shown in solid lines with X's. The uncertainty of the mean value of the measured lift and drag for each of the test cases was calculated. The uncertainty was found to vary between 4.7×10^{-5} and 1.3×10^{-2}. This gives us high confidence in our results.

At an angle of attack of 0° (Figure 3a), the redesigned wingsuit performs better than the original wingsuit from 31 m/s to 40 m/s, but both wingsuits have results lower than expected. At an angle of attack of 5° (Figure 3b) the redesigned wingsuit performs better at higher speeds than the original wingsuit, but worse at lower speeds. The L/D for the original wingsuit decreases from 1.6 at 22 m/s to less than 1.0 at 40 m/s.

For an angle of attack of 10° (Figure 3c), there is an obvious downward sloping for both the redesigned wingsuit and the original wingsuit. The original wingsuit also has a higher L/D, by about 0.2 for high speeds and 0.5 for low speeds. The same trend is seen at an angle of attack of 15° (Figure 3d). The L/D is still below what was expected based on data from Phoenix-Fly, which was supposed to be about 2.5 at speeds of around 38 m/s.

At angles of attack of 20° and 25° (Figure 3e and 3f, respectively) we have nearly identical trends. Both the redesigned wingsuit and the original wingsuit have decreasing L/D values for increasing speed. It is noted that the L/D for the original wingsuit at 22 m/s and 27 m/s is higher at an angle of attack of 20° than it is at 25°, while at higher speeds the L/D is higher for 25° than for 20°.

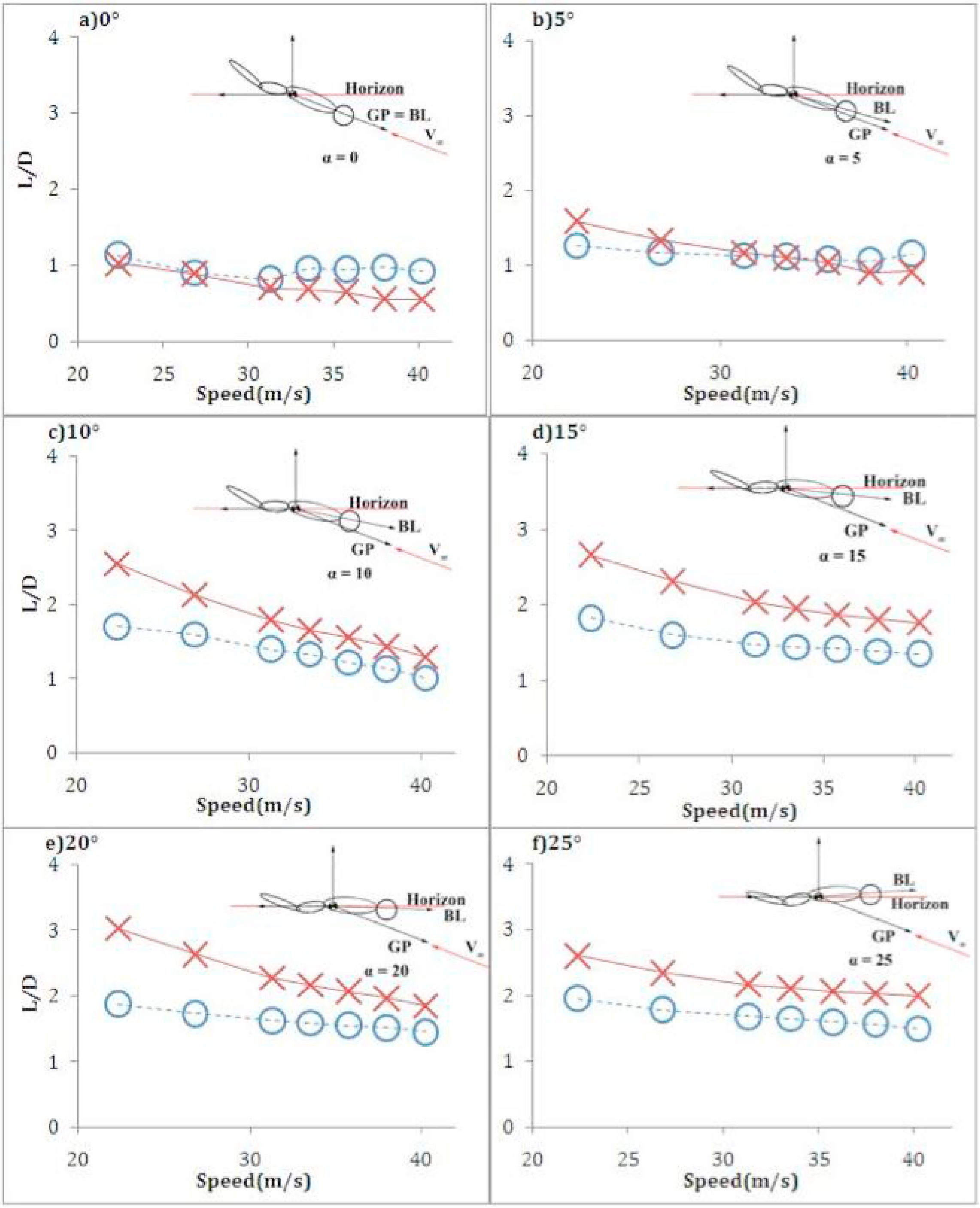

Fig. 3. L/D vs. speed for angles of attack (a) 0°, (b) 5°, (c) 10°, (d) 15°, (e) 20° and (f) 25°. The original wingsuit results are shown as a solid line marked with X's. The redesigned wingsuit results are shown as a dashed line marked with O's. In the upper right corner of each plot is a graphic depicting the flight angle.

7. Discussion

In the majority of the test conditions, the redesigned wingsuit has a lower lift-to-drag ratio when compared to the original wingsuit. This result was due to the redesigned wingsuit generating higher lift (as expected), but also generating much higher drag, which while not predicted is understandable. Higher lift was expected due to the increased lifting surface area with the addition of the forward wings. Higher profile drag was expected but not in the quantity seen in the results. We also expected the addition of the forward wings to improve the flow around the leading edge of the arms and thus reduce the drag. The 0° angle of attack scenario is the only test where the redesigned wingsuit had a higher lift-to-drag ratio because the forward wing increased the lift while not increasing the profile drag. However, for the higher angles of attack, the forward wing's larger cross-sectional area visible to the oncoming flow caused an increase in profile drag, resulting in a much higher drag.

When looking at lift and drag values separately, an interesting trend is observed. We see approximately 15-20% more lift generated by the redesigned wingsuit than by the original wingsuit. While at the same time, the redesigned wingsuit generates about 55-60% more drag than the original wingsuit. Looking at the lift values we can say the redesigned wingsuit is an improvement. The redesigned wingsuit will have a longer fall time at the cost of a shorter flight range.

While the increased lift and increased drag that the redesigned wingsuit generated was not desired for this project, it may be desirable for other purposes. Another goal of wingsuit enthusiasts is to land without a parachute. When using current wingsuits, the pilot has too much forward velocity when approaching landing. Thus a wingsuit, such as the redesigned wingsuit, with a higher lift and drag may allow skilled pilots to land without a parachute.

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