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(Review Article)

Design and evaluation of inflatable wings as a secondary wing during mid-flight emergencies

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Abstract

Inflatable wings have been demonstrated in many applications over the past five decades, including aircraft, UAVs, airships, and missile stabilization surfaces. Recent advancements in high strength fibers and rigidisable materials have enabled higher performance designs for modern application. This paper presents the methodology applied to optimally design an inflatable wing suitable to act as a secondary wing in case of mid-flight emergencies, with the help of widely known software, namely, Glenn research center by NASA. In this study, the application and efficiency of inflatables as an emergency wing in different aircrafts is successfully explored. Under the student foil interactive, the various design parameters of both airfoil and ellipse have also been explored to derive the benefits. By considering an ideal case where the camber would be zero, the analysis of the relationship between the angle of attack, thickness and lift to drag ratio have been closely observed and noted. In the further parts of this paper we will come to a conclusion about what parameters will be fit for an inflatable to behave as an emergency wing.

Keywords: Lift to drag ratio; Angle of Attack (AoA); Elliptical; Airfoil; Camber

1. Introduction

The first structure of inflatable wings was proposed by Taylor Daniel in 1930 which consisted of inflatable tubular segments connected to a fuselage. Unfortunately, due to lack of practical usage, his interventions couldn't gain much fame despite its safety record.

Inflatable wings are suitable for loitering munitions due its lightweight feature, cabinet storage volume and rapid deployment. It is known to have reduced the I-2000UAV's weight by 42.7%. Due to high flexibility, the inflatable wing can achieve adaptive change in span length and even rapid discard by pneumatic actuation.

For any aircraft to be in flight it's important to have a high lift to drag ratio. Each wing needs to be tilted at an angle to generate lift which is known as "Angle of Attack". While the wing is at an angle in the air, two forces are acted upon to lift the wing up and to push it down. These act perpendicularly upward and perpendicularly downward. Therefore since lift and drag are generated at the same, the force of lift should always be comparatively greater than that of drag. This lift to drag ratio depends on various factors such as material of the wing, speed which is controlled by the propulsion systems, size of the wing, design and angle of attack.

This paper proposes the efficiency of inflatable wings as a secondary wing which can be used during flight emergencies and to which aircrafts it can be deployed on, to show maximum effectiveness. The scope of this research can lead to

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adapting this method proposed to space aircrafts in the future. Implications for future research with modified materials can also be explored. However, using this approach for supersonic flights is not coherent.

2. Methodology

In this case, the speed of the aircraft will be reduced by a great amount (150 mph) and an average height of 25,000ft. The inflatables that are placed inside the fuselage or above the main wing will inflate with helium during the failure of the wing or any kind of emergency which leads to the crashing of the airplane. The method proposed here aims at optimally finding the best suitable wing, fit for inflatables when the aircraft is dealing with a failure scenario, it is done so by altering the angle of attack at a set of different angles for two types of airfoils-airfoil and elliptical- to check which position possesses a relatively higher lift on each case. The size of the inflatable wing in terms of chord, span and area (in ft) are set to match the dimensions of the main wing itself but altering the wingspan. Here we have taken the dimensions of a Boeing 777: chord =10.3, span = 104 ft, area 1071.2, aspect ratio = 10.097.

The parameters that are predominantly being assessed over here are the angle of attack, shape of airfoil and lift to drag ratio. It has been observed that the variation in the lift to drag ratios with respect to the angle of attack of both ellipse and airfoil shapes is at different rates. However, a conclusion can be drawn that with an increase in angle of attack, there’s a consequent decline in the lift to drag ratio, although the ratio increases to 18.874 at 5.6 degrees but declines further. A similar observation is seen with the elliptical airfoil where it increases upto 17.703 at 3.4 degrees and then starts to decline. therefore. A high lift to drag ratio would be perfect to work with inflatable wings.

The greatest lift to drag ratio achieved with the airfoil shape is 18.874 at 5.6 degree, and 17.703 at 3.4 degrees with the elliptical airfoil.

3. Literature Review

The main purpose of this paper is to cite the conditions to be met by an inflatable to be in action during an emergency for safe landing. The best position for the inflatable wings to be positioned is either inside the fuselage or above the main wing. Midwings, positioned in the middle of the fuselage, leave the airplane belly free of spars, with room for bombs or cargo. The best option to inflate the wings is to do it by the use of helium as it has proved to be the best method in previous studies and experiments.

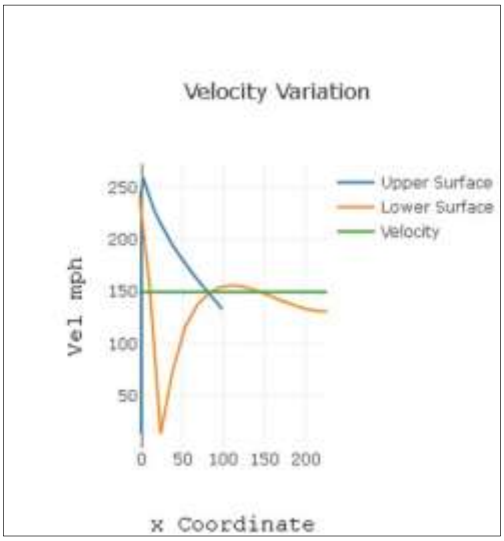
According to a research paper published by University of Kentucky on doctoral dissertations, unlike traditional wings, inflatable wing skins tend to wrinkle. This wrinkling creates a softening nonlinear effect during bending, and when paired with the high structural damping of the inflatable wing, it can lead to limit cycle oscillations. On the other hand, a significant challenge for inflatable wing designs is the absence of roll control actuators, which are present in traditional rigid wings equipped with flaps and ailerons. This issue can be addressed through various approaches. One potential solution involves using a servo actuation technique to deform the wing shape for roll control, leveraging the inherent deformability of inflatable wings. To assess the wing's capabilities, preliminary information was necessary, prompting studies to evaluate its aerodynamic performance and stored volume.

Because the wing lacks structural elements to maintain stiffness, it requires high inflation pressure. It's crucial to sustain this pressure, as the air pressure is what keeps the wing properly shaped.

4. Result

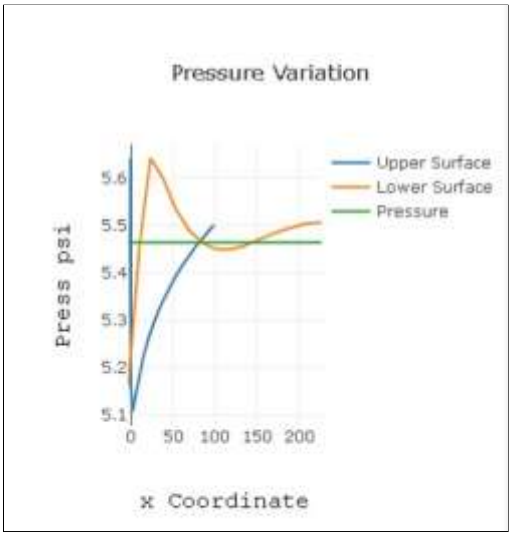
The variation of many factors such as density, wings span, altitude, camber, AoA, and thickness have been assessed with respect to drag and lift which is presented through graphs below. By adhering to the simulation setting presented in the methodology above, these graphs show the variation accordingly.

Graphs of variation in pressure and velocity are plotted. Additionally, a graph of drag polar is also presented below.



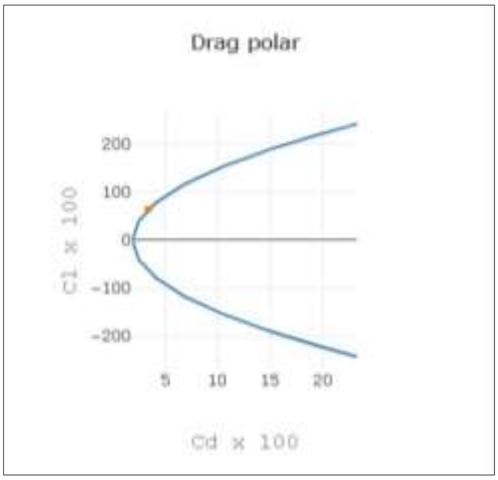
1.

Velocity variation of of the upper surface, lower surface of an airfoil is illustrated above. The plot illustrates how the velocity changes along both surfaces, with a notable peak on the upper surface and contrasting trends on the lower surface. The reference line for overall velocity is shown for comparison.



2.

The plot highlights differences in pressure distribution on both surfaces, with a sharp initial peak on the upper surface and a smoother trend on the lower surface. A reference line for the overall pressure is included for comparison.



3.

The graph shows how Cl varies with increasing Cd, illustrating aerodynamic efficiency. A marked point on the curve indicates a specific operational condition or design point.

The results of lift and drag versus factors like speed, altitude, thickness, wingspan, angle, camber, density are also assessed.

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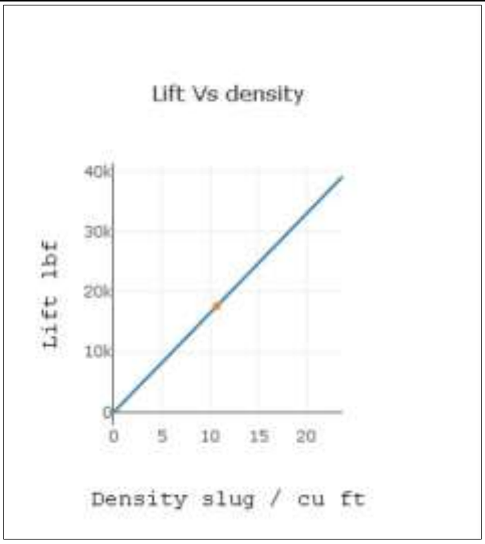

4.
The graph shows the variation of lift with density.
It is observed that lift increases uniformly with density.
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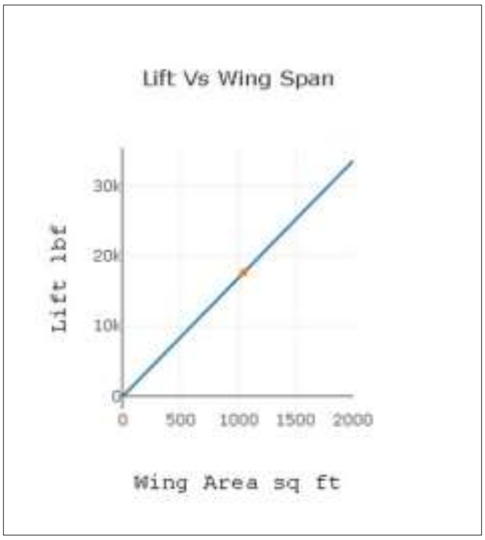

5.
The graph shows the relationship of lift with wingspan
It is observed that lift increases uniformly with wingspan.
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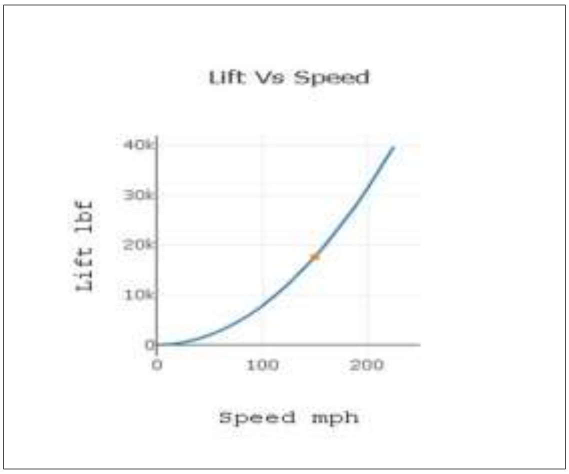

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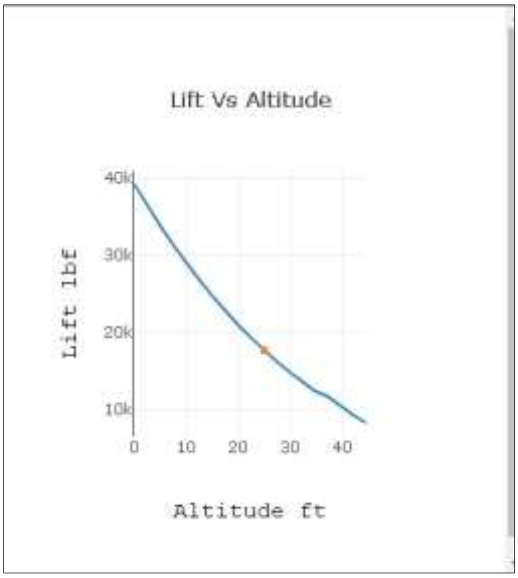
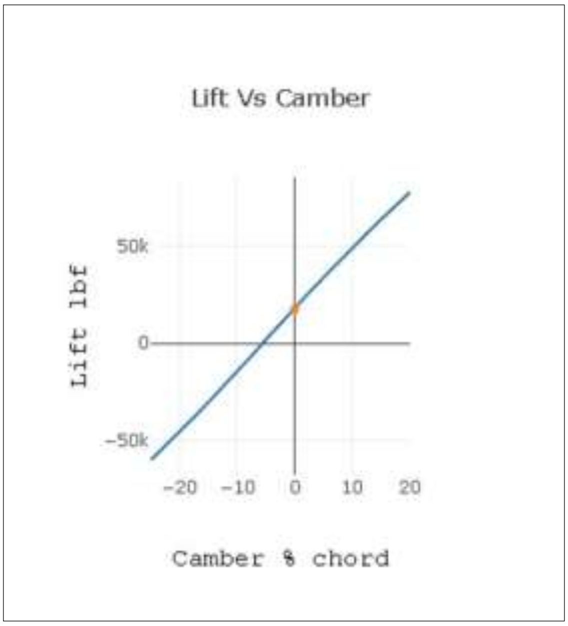
7. 

The lift vs altitude graph shows a decreasing non uniform trend. The non-uniform decrease in lift with altitude is primarily due to the reduction in air density and changes in aerodynamic conditions, leading to complex interactions that are not linear across all altitudes.

8. 

The lift vs camber graph shows that increasing the camber of an airfoil leads to a proportional increase in lift. This indicates that camber is an effective way to enhance lift generation.

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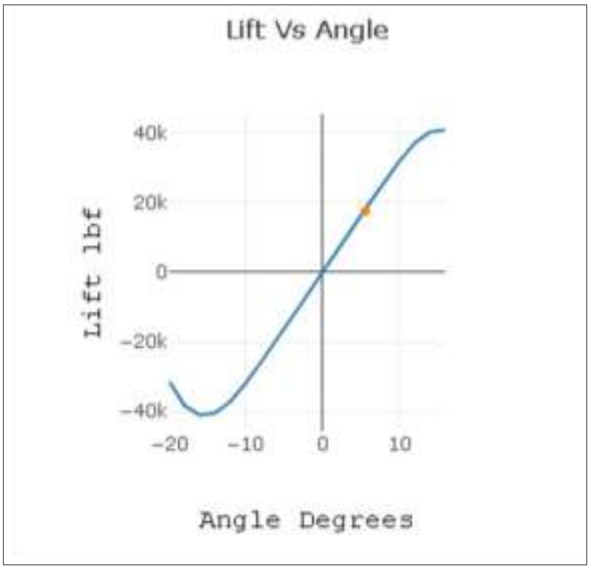
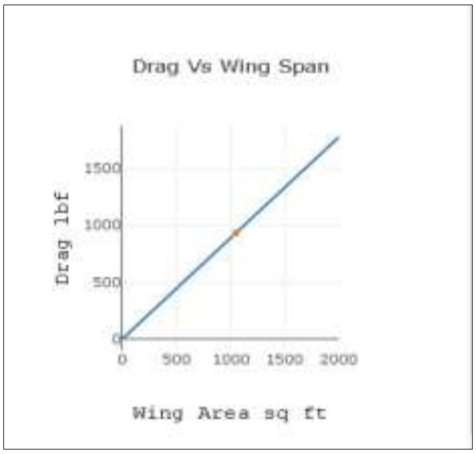


9.

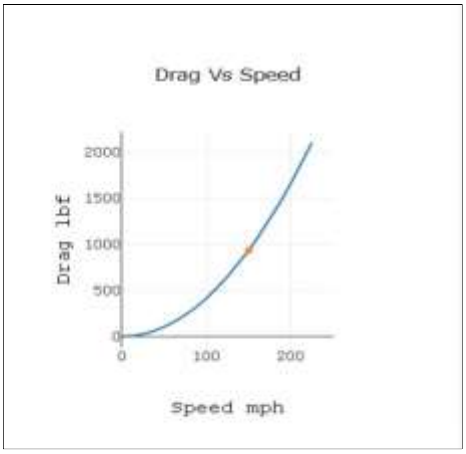
The lift vs angle of attack graph portrays that the upward slope of the parabola indicates that as the angle of attack increases from a low value, lift increases significantly. This is the effective range of AoA(angle of attack) where the airfoil is generating lift efficiently. The parabolic shape highlights the nonlinear nature of the lift response to changes in angle of attack. This means that small adjustments in AoA near the optimal point can lead to significant changes in lift, but the same adjustments at higher AoA can lead to rapid loss of lift.

10.

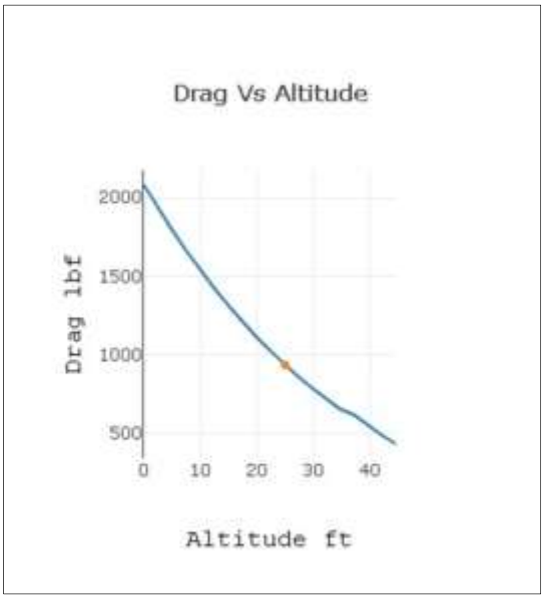
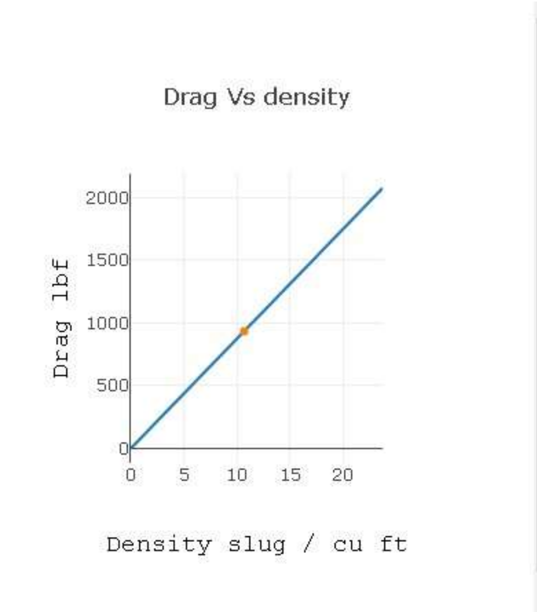


The graph shows the variation of drag with wingspan. Drag vs wingspan and density shows a uniform trend.

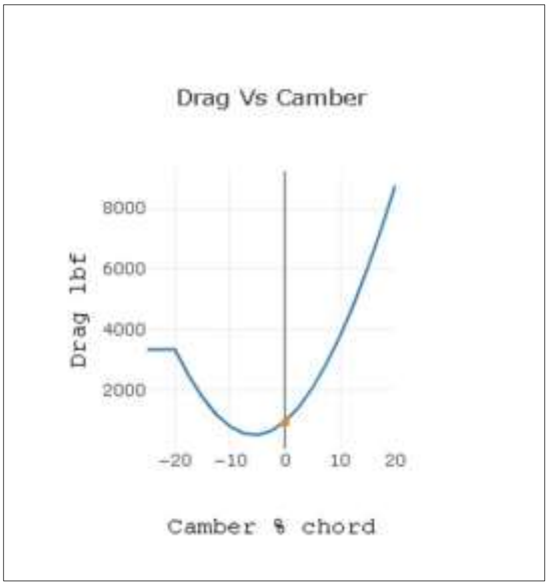
11.



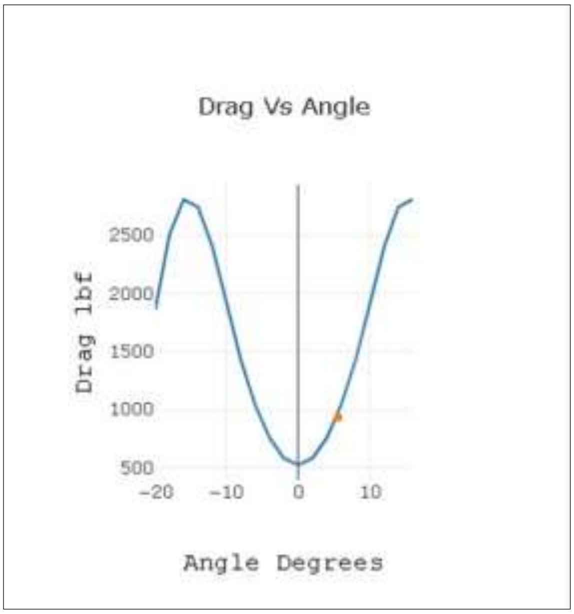
The graph above shows the relationship between drag and speed. Drag vs speed shows a non uniform trend.

12. 	13. 
The graph illustrates the variation of drag with altitude. the drag vs altitude shows a decreasing non uniform trend.	The graph illustrates the relationship between drag and density. Drag vs density shows a uniform linear trend similar to lift vs density.

14.



In the drag vs camber graph,the upward slope of the parabola indicates that as camber increases from a low value, drag initially rise.The parabolic relationship highlights the trade-off between lift and drag in airfoil design. While increasing camber can enhance lift, it can also lead to higher drag, necessitating careful optimization for performance.

15. 

A parabolic graph of drag versus angle of attack indicates that drag increases with AoA, identifies an optimal angle where drag is minimized, and underscores the importance of understanding drag behavior in relation to lift during flight to optimize performance and efficiency.

The thickness in both graphs is constant, concluding that it has no effect on either lift or drag.

5. Conclusion

With our findings in the above procedures, it is prudent to conclude that the best shape which can be used in this circumstance is an airfoil shape. The shape of an airfoil is engineered to leverage the natural reaction of airflow when it encounters disruption. As air moves over an airfoil, two main effects happen: a positive pressure creates a lifting force from beneath the wing, while a negative pressure generates an additional lifting force from the area above the wing. Deploying an inflatable possessing design, Joukowski airfoil; angle of attack of 4.9 degrees, camber 0%,Thickness = 12.5% chord, chord = 10.1 ft span 104 ft, density = 0.001067 slug/cu ft, pressure = 5.462 lb/sq in, temperature = -30 F ,speed at 150mph, lift = 17620 lbs, drag = 934 lbs, surface area = 1050.40 sq ft would produce the maximum amount of lift to drag ratio of 18.874. It is important to note that these simulations are done with respect to emergency flight conditions. However for other special or normal conditions, it is recommended to assess the parameters accordingly. This study would present an idea for future research on inflatable wings' application on other aero-dynamic structures and to improvise or create other designs exclusively for inflatable wings.

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