Airfoil Shape Study on High Performance Glider Flight

--A simple airfoil design kit and and possible AI agent training on airfoil optimization

Fig [1]. Airfoil Design on the Cardboard Drone. Composite image from the SYPAQ cardboard drone model

Introduction:

Background research:

In my previous study in science fair, my project is focusing on which factors affect the distance of flying paper airplane. I listed the possible options(airplane shapes, design parameters, materials, etc.) and draw a conclusion. If modify some size of model, the tail length, the wing length, or the angle of the hanger, which may optimize the model to get longer distance. As expected, I took more investigations on the design geometric data of a simple airplane model, glider. However, the glider design is complicated in terms of too many aspects. Based on the valuable knowledge learned online, I chose the airfoil as a primary design variable to study the performance of the glider. Moreover, the real gliders(paper/cardboard airplanes) are not easy to handmade to be tested and verified to a result or conclusion. In my study of the previous science fair, I tried many paper airplane(and cardboard airplane) flight testings(changing the shape of wings), which couldn't give reliable results due to the launch condition and handmade error. Instead, a way to verify the method and get a better performance flight glider in terms of airfoil are some good virtual simulation tools. Even though the parameters and functions related to mathematics are complex and hard to handle in the short term, I would utilize those kits to do simulation and simultaneously consider of studying machine learning tools to get a better design result. [1][2][3][4].

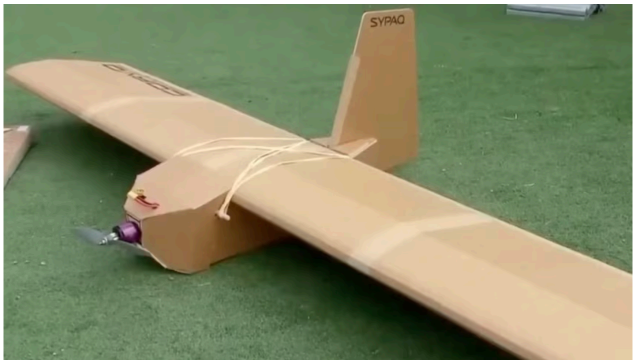
Following the main stream theories, the wing's shape would be a primary design part for the airplane's flying performance. Therefore, for the design parameters of the glider's wing, I simplify the design parameters of the 3-dimensional wing and choose the 2-dimensional airfoil(the cross-section of the wing) be a critical design parameter for the study.

So, my project starts from learning the airfoil's geometry and theories, to analyze the force acting on the airplane, simulate the flying process. This process is, applying the design model geometric data in visual 2D model, minimizing the error of hand-made work, analyzing the force equivalence on the model, to research a clear explanation via Newton mechanics whether some airplane model with certain material would fly the longest distance, to achieve the best performance.

Considering the experimental track is very hard to distinguish(it isn't easy to be duplicate because when the experiment environment is different, the precision of some controlled data would affect the results.), the available simulation software tools, virtual toolkits could simulate the modes and tracks of the glider, facilitate the verification of my project's result(I prefer/have to use this way). Even though there are lots of already implemented methods on this topic, my efforts are providing different tools to illustrate the research results via an interactive way(an online tool) and instruct the design options for many model applications, furthermore, develop Ai tools deployed to optimize the design process of the glider.

Inspirations:

The Australian cardboard drones became a critical innovation. The drones' wings are a typical airfoil design. If it could be designed well, the glider or the drones have high performance, the applications could bring more business benefits[5][6].
https://www.businessinsider.com/ukraine-is-using-a-cheap-flat-pack-cardboard-drone-australia-2023-8
https://www.abc.net.au/news/2023-09-03/ukraine-war-australian-made-cardboard-drones-russia-warfare/102804120



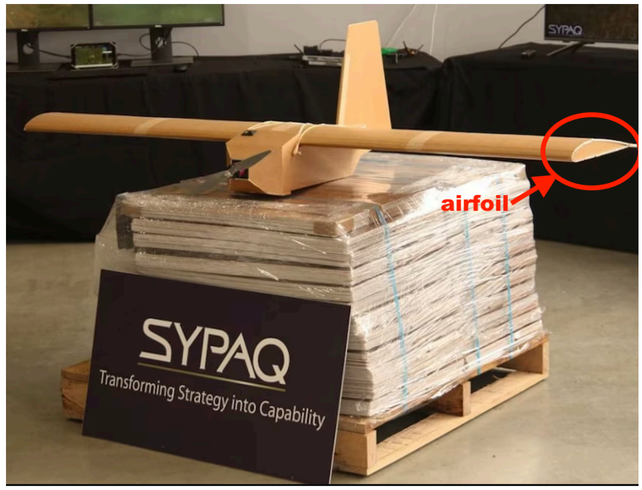


Fig [2]. Australian SYPAQ cardboard drones in cheap flat pack and wide application.

Materials:

- NASA online resources: Glenn Research Center
- Github open sources for the simulation tools
- Online API tools
- Available AI training tools.

Hypothesis:

Using these information, even though we thought the lighter airplane with less gravity may stay much longer in the air, the airplane won't fly longer distance or stay more time in the air due to the unstable flight. Air resistance is more complicated than what I thought. In ideal scenario, the Newton mechanics is the basis of the design of the high-performance glider/drone. some airplane models with certain material(paper, cardboard, other lighter materials) would fly the longest distance, to achieve the best performance, the simulation results would be reliable to be the criteria to show the high-performance of the glider.

Procedure:

1. Terminology in wing model

A wing geometry definition [3] is one of the chief factors affecting airplane life and drag. Study and list airfoil's terminology used throughout the airplane industry cited at NASA Glenn's website.

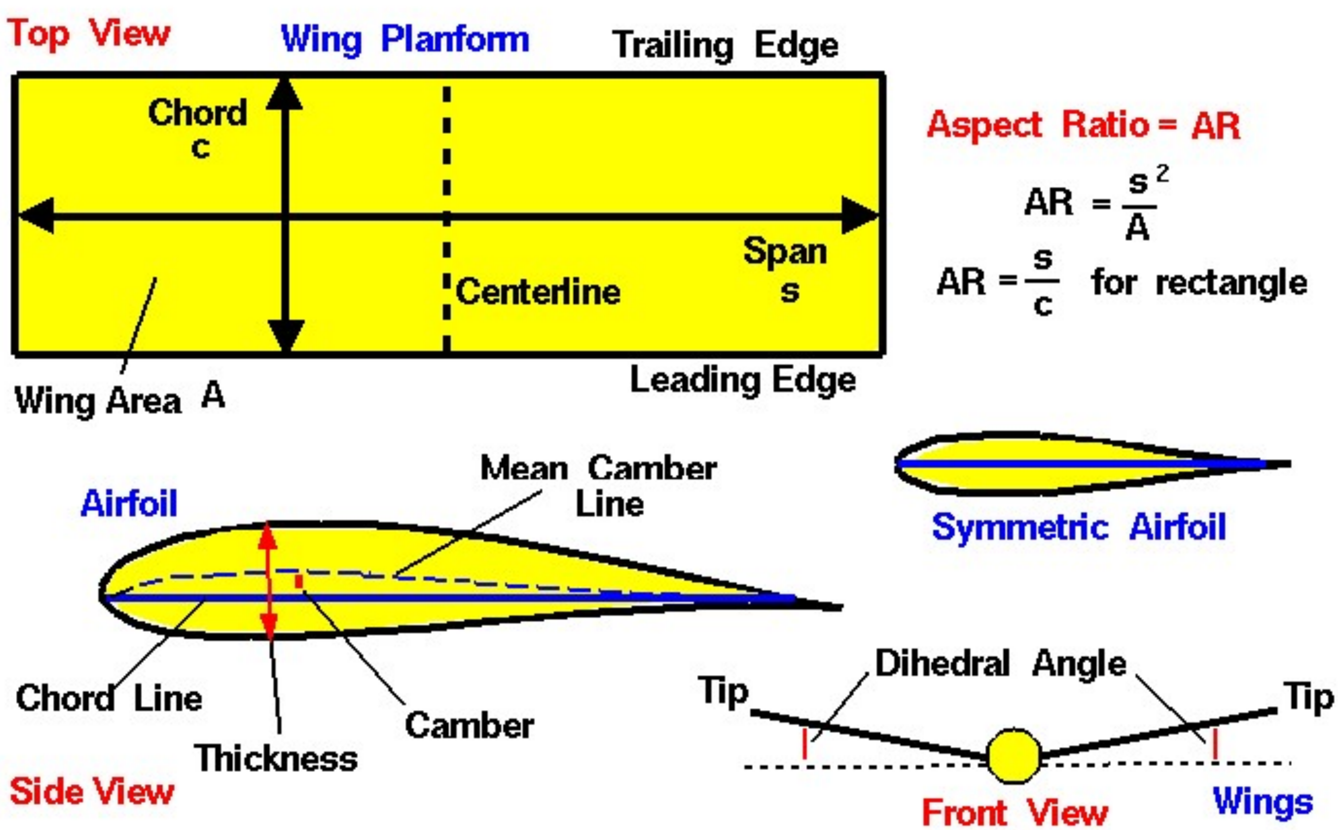


Fig [3]. Wing Geometry Definitions from NASA Glenn's website.

A measure of the curvature of the airfoil. The mean camber line is an imaginary line which lies halfway between the upper surface and lower surface of the airfoil and intersects the chord line at the leading and trailing edges. The design parameters are the relative relationship among thickness, camber and chord line of airfoil. If modify the parameters of airfoil, may optimize the model to get longer distance.

Table [1]. Wing and Airfoil differences:

Aspect	Airfoil	Wing
Nature	2D cross-section	3D structure
Focus	Aerodynamic shape efficiency	Lift, stability, and control
Components	Leading/trailing edges, camber	Span, sweep, dihedral, flaps
Application	Used in wings, blades, etc.	Entire lifting surface

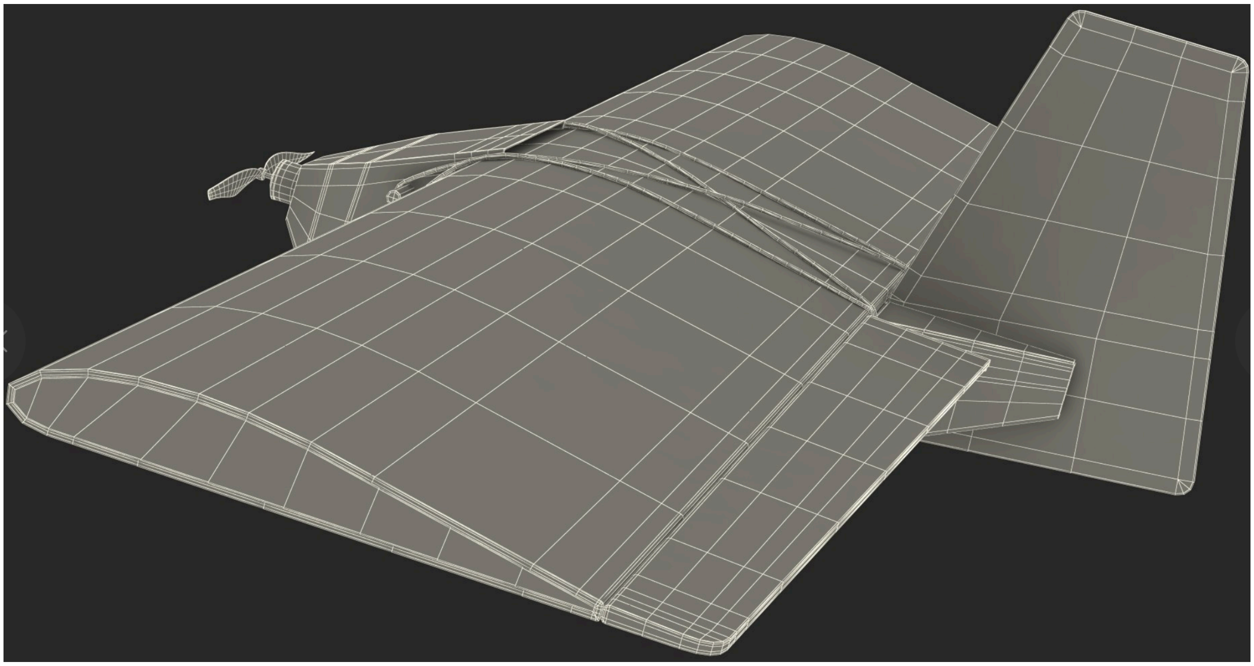


Fig [4]. cardboard drones 3D model with mesh.[7]

2. Changes in goal/purpose/objective

For a solid body immersed in a fluid, the “point of contact” is every point on the surface of the body. The fluid can flow around the body and maintain physical contact at all points. The transmission, or application, of mechanical forces between a solid body and a fluid occurs at every point on the surface of the body. And the transmission occurs through the fluid pressure.

In reality, the airplane immersed in the air, the air flow around and maintain physical contact at all points on the surface. Those forces applied at every point on the surface of the wings, and the transmission occurs through the air pressure.

Like the shape of a bird’s feather cross-section, the specific shape of a cross-section of the wings could be designed to generate lift when air flows over it. How air interacts with the surface, creating lift or thrust based on principles like Bernoulli’s principle and Newton’s third law. The 2D shape is designed to optimize aerodynamic properties like lift, drag and stability. The shape of wing’s cross-section(airfoil) is my studied model incorporating components like the leading edge, trailing edge, chord line and camber.

3. Changes in methodology

$F=P*A$

Pressure(P) acts normal to the surface of the wings. So the normal direction changes from the front of the airfoil to the rear and front top to the bottom. To get the net force over the wings, we sum the contributions from all the small sections.
F=Sigma(P*n*dA).   dA: Delta A, the incremental area.

In the limit of infinitely small sections, the integral of the pressure (all round the body) times the area around the closed surface (S dA)

For a fluid in motion, the velocity has different values at different locations around the airplane. The local pressure is related to the local velocity, so the pressure varies around the closed surface and a net force is produced[001], the variation of the pressure around the airfoil is solved via Euler equations. The net force normal to the flow direction is lift, the net force along the flow direction is the drag. The aerodynamic force acts through the average location of the pressure variation is the center of pressure.

Velocity Distribution & Bernoulli's equation.
For an ideal fluid with no boundary layers, the surface of an object is a streamline.
If the velocity is low and no energy is added to the flow, we can use Bernoulli's equation along a stream line to determine the pressure distribution for a known velocity distribution. Furtherly to solve a series of mass, momentum and energy for the fluid passing the structure will help solving simplified versions of the equations to calculate the velocity and pressure[4].

Pressure forces act perpendicular to the surface.

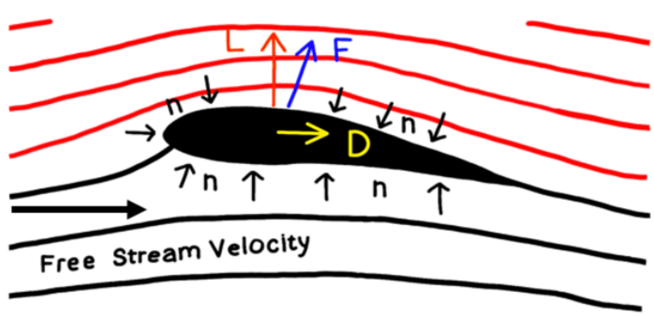
Force on the body is the vector sum of the pressure times the area around the body.

$$\underset{F}{\rightarrow} = \sum p \underset{n}{\rightarrow} \Delta A$$

$$\underset{F}{\rightarrow} = \oint p \underset{n}{\rightarrow} dA$$

$$Lift = L = F_{normal}$$

$$Drag = D = F_{streamwise}$$



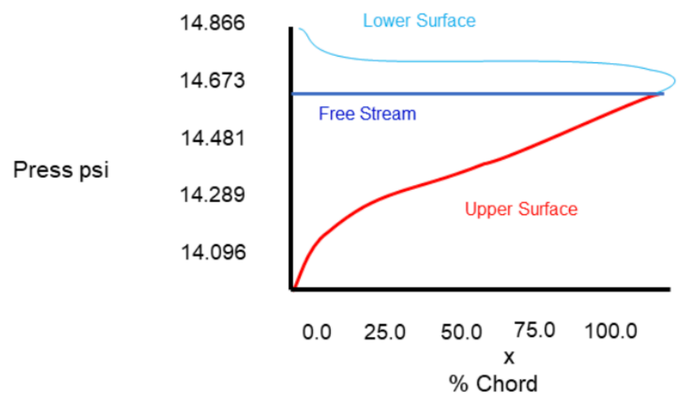


Fig [5]. NASA Glenn Research Center. Aerodynamic Forces illustration [2]

4. Variable studied.

Investigate how an aircraft wing produces lift and drag by changing the values of different factors in airfoil that affect lift and the factors that affect drag.

Design variables of the airfoil, Camber, Thickness, the angle of attack of the cross section;

Outputs:: Surface Pressure, Surface Velocity, Lift force, Drag force, Coefficient of Lift(Cl), Coefficient of Drag(Cd), L/D ratio.

Reflective & Application

A simple App for showing the schematic drawing of the airfoil design, adding some options to control and outputting the particle traces to form a flow line, illustrating the surface pressure and the relative sensitivity of lift and drag to the input design variables.

Others:

The Reynolds number is the ratio of inertial forces to viscous forces and affects the calculated value of the lift and drag. Reynold's number and lift to drag ratio;

The aspect ratio is defined to be the square of the span divided by the wing area and is included in the calculation of induced drag.

Input variables:

the geometry of the airfoil without flow field.

Results:

Discussion:

Simulation on the Airfoil models:

Reference Citation:

[1]https://www.grc.nasa.gov/WWW/K-12/airplane/index.html

[2] aerodynamic forces https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/aerodynamic-forces/

[3]Wing Geometry Definitionshttps://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/geom.html#:~:text=The%20straight%20line%20drawn%20from,called%20the%20mean%20camber%20line

[4] Aerodynamic forces https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/aerodynamic-forces/

[5] Cardboard drones news https://www.abc.net.au/news/2023-09-03/ukraine-war-australian-made-cardboard-drones-russia-warfare/102804120

[6] Business insider. Cardboard drones are flat-packed https://www.businessinsider.com/ukraine-is-using-a-cheap-flat-pack-cardboard-drone-australia-2023-8

[7] cardboard drones 3D model with mesh https://www.turbosquid.com/3d-models/3d-model-logistics-cardboard-drone-sypaq-2157515