# Preliminary Aerodynamic Study

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## 0.1 Rationale

The airfoil is the heart of an aircraft. Selecting the correct airfoil allows us to predict the lift, drag, and pitching moments produced by the wing. The lift and drag is obviously important in flying the aircraft, and determining its cruising speed, orientation and power consumption. The pitching moments should be used in conjunction with the location of the center of mass to determine the sizing of the aircraft tail. Too small of an aircraft tail and there is not enough control authority, too large of a tail and the aircraft performance suffers.

## 0.2 General Airfoil Comparisons

### 0.2.1 "Fat" Airfoils

A "fat" airfoil is going to be defined as an airfoil with a large radius for its leading edge, is generally thick, and has a large amount of camber.

#### Advantages

So the large camber of the airfoil allows it to produce alot of lift at zero angle of attack. The large radius at its leading edge allows the airflow to remain attached, which increases the stall angle of the airfoil, allowing for a higher maximum lift coefficient. The correct thickness distribution is helpful in preventing flow separation. A thick airfoil has good stall characteristics. Stall will occur first in the trailing edge of the airfoil and progressively move to the leading edge. The loss of lift is gradual and pitching moments do not change by too much

#### Disadvantages

It has alot of drag. The induced drag is higher because of its lifting capabilities, but its viscous drag is also higher because it has more surface area due to its camber and thickness. The pitching moments about the aerodynamic center is also great due to the camber of the airfoil.

### 0.2.2 "Thin" Airfoils

A "thin" airfoil is going to be defined as an airfoil with a lower radius on its leading edge, is generally thin, and has a lower amount of camber.

#### Advantages

These airfoils can suppress turbulence, maintaining laminar flow and getting very good lift to drag ratios. These airfoils typically produce a low amount of lift and also produce very mild pitching moments.

#### Disadvantages

They cannot produce as much lift. If they are taken out of their laminar bucket, drag will increase and lift will fall quickly, this is because laminar flows are more prone to separation. They also exhibit terrible stall characteristics. Separation occurs complete and instantly, loss of lift is instant, and bad pitching moments will instantly appear during stall.

## 0.3 Initial Airfoil Selection

Based on the design requirements, the aircraft needs to have a stall speed that is as low as possible, which drives our wing area to be large. However, due to the geometric requirements of the craft, there is a limit to how large our wing area can be. So, if we make sure our wing produces as much lift as possible, we can still have a reasonable wing area with a really low stall speed. So, we must prioritize high-lift capable wings. Therefore, we should choose "fatter" airfoils over their "thinner" counterparts.

Here is how we are going to choose our airfoils. We are going to have a list of airfoils just by visual inspection of which ones look "fat" for the high maximum lift coefficient and gentle stall characteristics. Then, we are going to run `xflr` on it and do wind-tunnel testing to rule all the others out and choose the one that best suits our needs. The selected airfoils are:

| Airfoil Name | Max Thickness | Max Thick Loc | Max Camber | Max Camber Loc |
|---|---|---|---|---|
| Eppler 420 | 14.3 | 22.8 | 10.6 | 40.5 |
| Eppler E423 | 12.5 | 23.7 | 9.5 | 41.4 |
| S1223 | 12.1 | 19.8 | 8.1 | 49.0 |
| S1223 RTL | 13.5 | 19.9 | 8.3 | 55.2 |
| Chuch Hollinger CH 10-48-13 | 12.8 | 30.6 | 10.2 | 49.3 |
| Curtiss CR-1 | 12.2 | 24.0 | 4.7 | 42.0 |
| Drela DAE11 | 12.8 | 32.8 | 6.6 | 44.4 |
| Drela DAE21 | 11.8 | 32.0 | 6.6 | 43.7 |
| Drela DAE31 | 11.1 | 29.3 | 6.7 | 47.0 |
| Lissaman 7769 | 11.0 | 30.0 | 4.4 | 30.0 |

## 0.4 Airfoil Computational Analysis

$$R = \frac{\rho U L}{\mu}$$

Taking density of air to be $\rho = 1.225\,kgm^{-3}$, dynamic viscosity $\mu = 1.81 \times 10^{-5}\,kgm^{-1}s^{-1}$. Our stall speed was prescribed by the requirements to be around $V_{stall} = 4.572\,ms^{-1}$. Our chord length is predicted to be around $0.12\,m$ at the smallest part of the wing so to be safe, let us try to simulate for chord length of around $0.05\,m$. The `Python` script below is used to compute the Reynold's number,

```python
#!/bin/python
def R_Num(U, L):
    '''U here is the velocity, enter stall speed
    L here is the length, enter target chord length'''
    rho = 1.225 #Density in kg/m^3
    mu = 1.81*10**-5 #kgm^{-1}s^{-1}
    R = (rho*U*L)/mu #Compute Reynold's Number
    return R
```

The results of running the algorithm for the stall speed and minimum chord length gives the lower bound Reynold's number that the `xflr` simulations ought to be run at,

```
>>> R_Num(4.572, 0.05)
15471.546961325967
```

Running the algorithm for the same stall speed but at the predicted maximum chord length of around $0.4\,m$ gives us the upper bound Reynold's number that the `xflr` simulations should be run at,

```
>>> R_Num(4.572, 0.4)
123772.37569060773
```

For extra insurance, let us run our `xflr` analysis on the range of .

$$10000 \leq R_e \leq 150000 \tag{1}$$

## 0.5 Algorithm Development

1. Given an airfoil, we are going to run for a series of Reynold's number ranges prescribed based on equation 1.

2. For each of those Reynold's number, we are going to run simulations for a range of angles of attack. The range of the angles of attack is going to be high enough such that we can figure out the stall angle of attack and the corresponding maximum lift coefficient.

3. Now each airfoil for differing Reynold's number is going to have different stall angles and different corresponding maximum lift coefficient. Stall is a separation effect and it is a very bad regime to fly in. Therefore, we want to choose flight regimes without stall. This is just the limit of the airfoil.

4. This means that for a given airfoil, amongst all the different maximum lift coefficient due to Reynod's number variation, we will choose the minimum $c_{L,max}$.

5. We will also compute the average maximum lift coefficients for a given airfoil amongst its differing Reynold's number ranges justto compare that the minimum $c_{L,max}$ is not due to results that have failed to converge.

## 0.6 Airfoil Experimental Analysis

After that, we will run wind-tunnel testing on the remaining airfoils and choose our desired airfoil.

## 0.7 Wing Design

Need to figure out equation for flat plate boundary layer thickness
Need equation for aspect ratio
Need equation for taper ratio
An aircraft has to be designed such that it spends most of its time flying at an angle of attack that is best suited for its best L/D ratio for maximum efficiency.