Airframe Aerodynamic Design

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1 Introduction

This report covers the work done in learning how to optimize an airframe with specific parameters, using techniques and knowledge learned previously. The goal was to design an airframe that can lift 0.5 kilograms, has a wingspan no greater than 1.5 meters, and is stable.

2 Methods

The results of this research came from evaluating potential airframe solutions using VortexLattice.jl, as well as writing new functions to help in optimizing the airframe design. There were 4 functions that were used:

1. optimize_airframe() - this was the main function that optimized the airframe so that it met the specified requirements and was the most efficient; it employed the use of all the other functions in order to find the optimized airframe

2. aoa_coefficients() - this calculated the lift and drag coefficients for a given airframe design for a range of angles of attack.

3. vortex_lattice() - this was the function that performed all the necessary VortexLattice calculations for the other functions

In order to optimize the airframe, the process, discussed in the introduction to "Engineering Design Optimization" by Joaquim R.R.A. Martins and Andrew Ning, was followed. The objective function that was minimized was the equation used to calculate the velocity needed to produce the necessary lift to carry 0.5 kilograms (see equation 1).

$$V = \sqrt{\frac{L}{(0.5)(C_L)(\rho)(S_{ref})}} \tag{1}$$

- L - the lift needed to takeoff with 0.5 kilograms, in this case 4.905 N
- ρ - the density of the air (1.225 kg/m^3)
- S_{ref} - the reference area, in this case the wing area

The design variables that were altered in order to minimize that function was the mean aerodynamic chord length of the wing and the length from wing to tail on the airframe. The reason I chose these design variables was because I knew that the airframe that would generate the most lift would have the max wingspan possible (so in this case 1.5 m), and so altering the chord length would help me find the wing that needed the least speed to takeoff. I also chose the length from wing to tail as a design variable because I knew altering it would change how stable the airframe was. However, as I worked with these design variables, it was discovered that the greater the length from wing to tail, the more stable the airframe. For this reason, I put an upper limit on that length to be 2.0 m, so that the found airframe would be realistic. I also put a constraint on the aspect ratio of the wing, which was that it had to be greater than 2.0. The way that I found the optimal airframe was I changed those design variables together, so that it found the airframe that took off at the least velocity, but was the most stable. The efficiency of the airframe with different wing taper ratios was also evaluated by plotting the lift coefficient distribution against the optimal distribution, which was a ellipse. The ideal taper ratio was the one that produced a lift coefficient distribution closest to that elliptical distribution. This was done so that the final airframe design not only optimized my objective function, but was also the most efficient design.

3 Results and Discussion

After running the optimize_airframe() function, it found that the most optimized airframe was one that had the following characteristics (figure 1 shows what the design looks like):

- span length = 1.5 meters
- mean aerodynamic chord length = 0.7222 meters
- length from wing to tail = 2.0 meters
- taper = 1.0
- lift coefficient = 0.04616576328871639
- velocity needed to produce necessary lift = 12.653929077220258 m/s

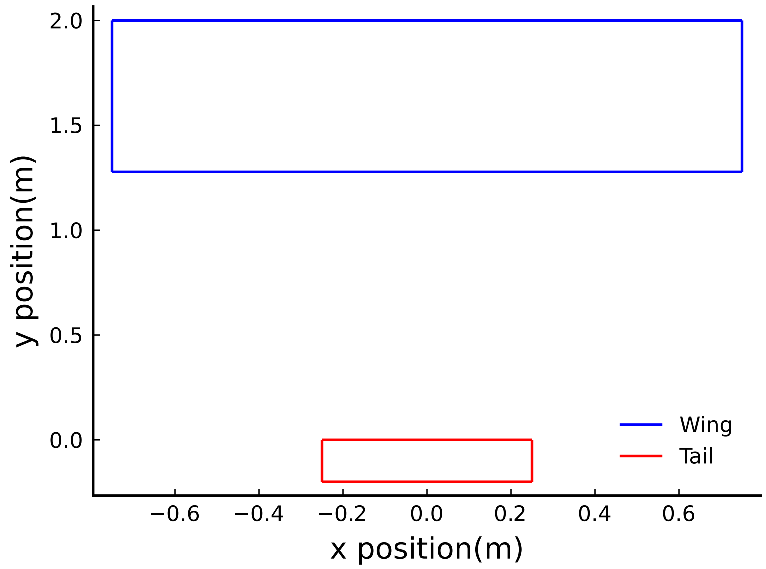

Fig. 1: *This figure shows the design of the optimized airframe.*

The aforementioned necessary lift was 4.905 Newtons. This number was found by multiplying 0.5 kilograms by 9.81 m/s^2, which is the acceleration due to gravity. It is also important to note that the optimize_airframe() function accounts for stability and makes sure that the airframe is the most stable, and so this airframe is the most stable one under the given constraints. In order to show that this airframe has been optimized, other airframes have been evaluated in order to show correctness.

3.1 Altered Mean Chord Length

When evaluating an airframe that has a mean chord length that is less than 0.7222 m (I used 0.6 m for comparison), it was found that the velocity needed to generate the necessary lift was 13.049496968197154 m/s, which is greater than than the velocity needed for the optimized airframe. This shows that airframes with smaller mean chord lengths are not more optimized, as they need a greater velocity to lift the 0.5 kilograms.

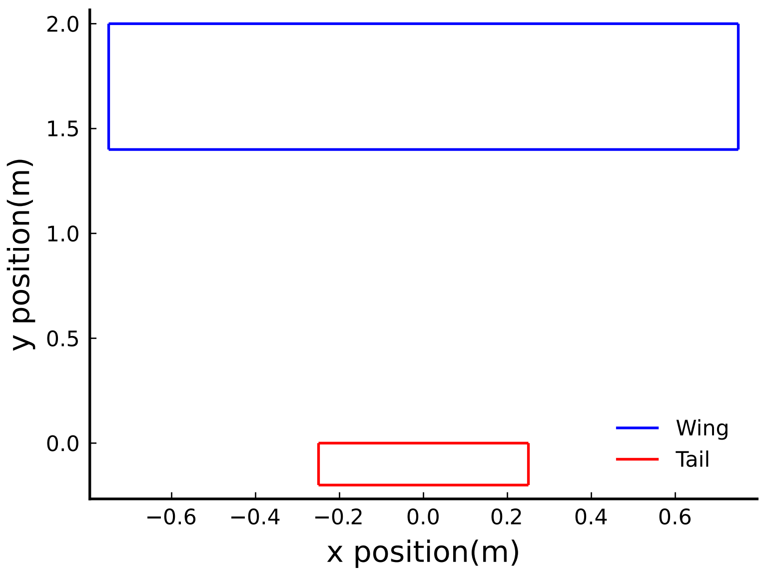

Fig. 2: *This figure shows the design of an airframe with a chord length of 0.6 m.*

An airframe with a greater chord length was not evaluated for comparison, because of the constraint I put on the aspect ratio. 0.7222 m was the largest possible chord length that kept the aspect ratio of the wing greater than 2.0.

Plots showing the lift coefficient vs. angle of attack and drag coefficient vs. angle of attack for these 2 designs are given (see figures 3 and 4).

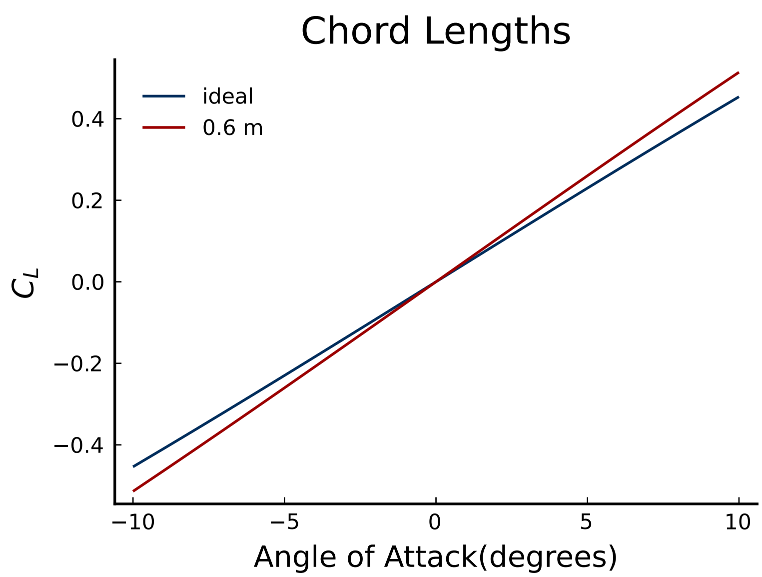

Fig. 3: *This figure shows the lift coefficients for varying angles of attack for the 2 designs evaluated using different mean chord lengths.*

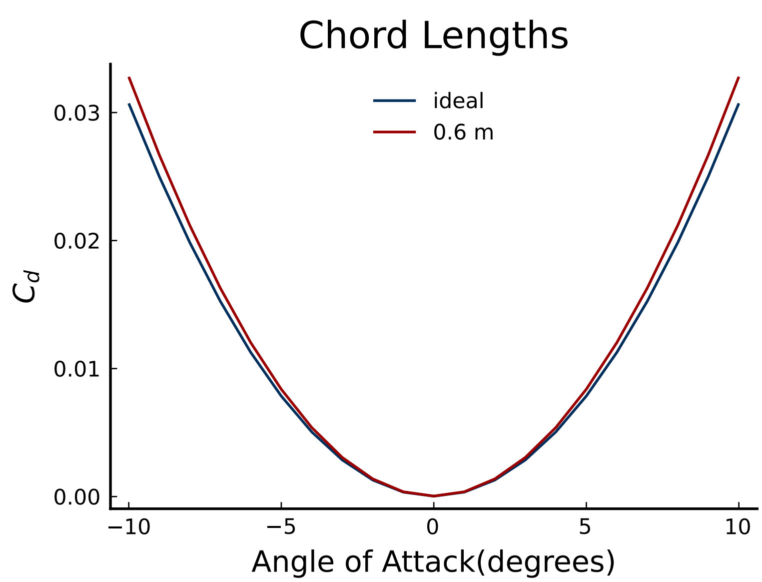

Fig. 4: *This figure shows the drag coefficients for varying angles of attack for the 2 designs evaluated using different mean chord lengths.*

3.2 Altered Length from Wing to Tail

When evaluating an airframe that has a length from wing to tail that is less than 2.0 m (I used 1.0 m), it was found that the velocity needed to generate the necessary lift doesn't change. However, the airframe is less stable as the yaw stability derivative(C_{nb}) is less than the yaw stability derivative for the optimized airframe. Therefore, as the length from wing to tail is decreased, the airframe becomes less stable.

Figures showing the lift and drag coefficients vs. angle of attack for the 2 designs are given (see figures 5 and 6).

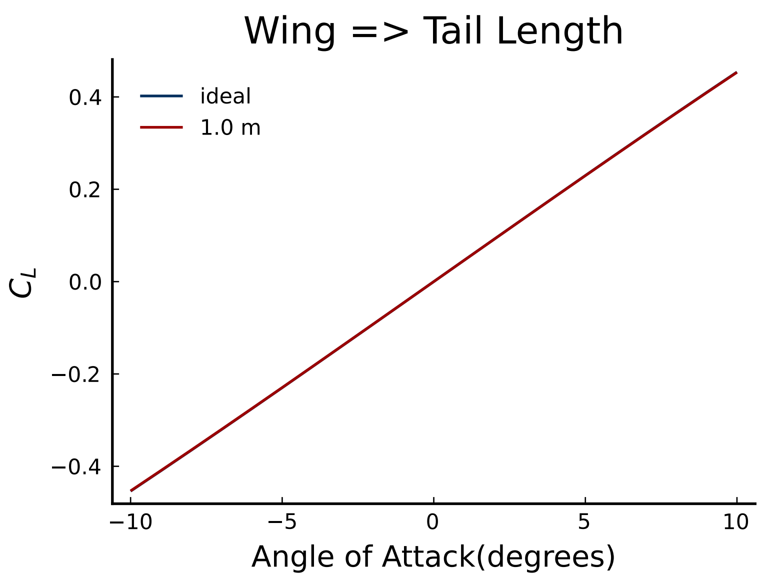

Fig. 5: *This figure shows the lift coefficient vs. angle of attack for the 2 designs evaluated.*

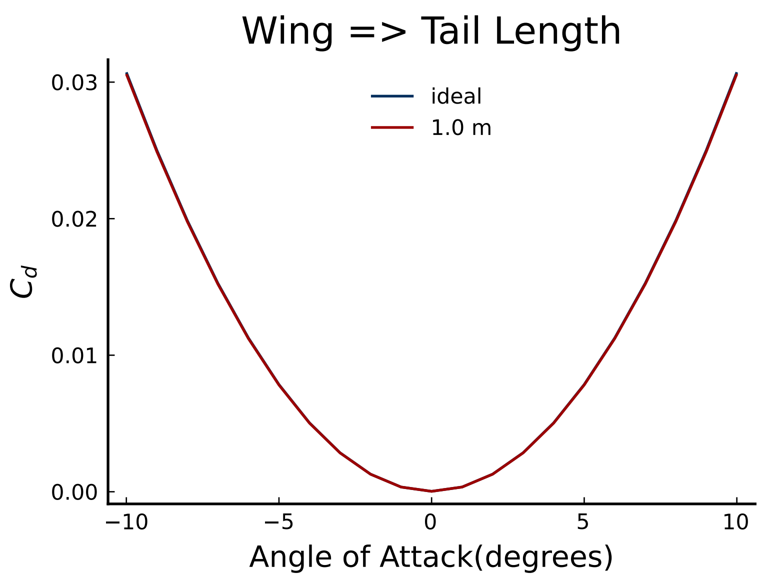

Fig. 6: *This figure shows the drag coefficient vs. angle of attack for the 2 designs evaluated.*

Figure 7 shows the design of an airframe with a length from wing to tail of 1.0 m.

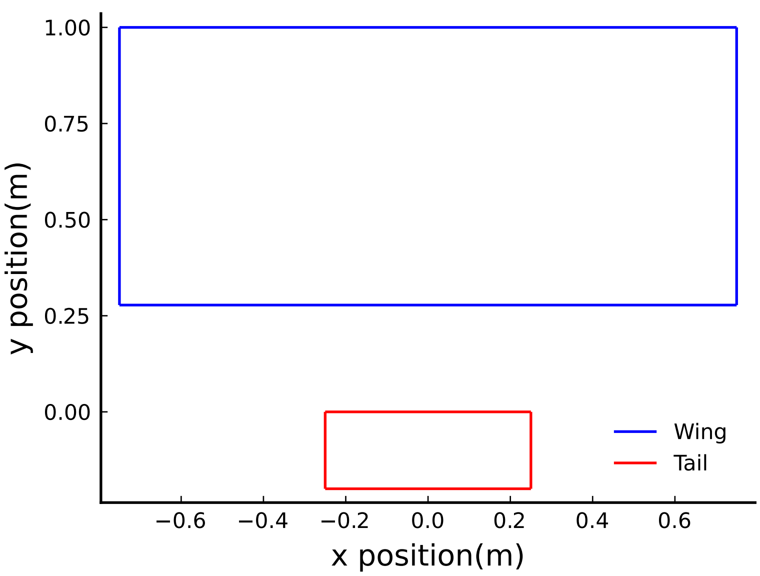

Fig. 7: *This figure shows design of an airframe with a length from wing to tail of 1.0 m.*

3.3 Altered Wing Taper

The wing taper ratio of an airframe is found using equation 2.

$$Taper\ Ratio = \frac{tip\ chord\ length}{base\ chord\ length} \tag{2}$$

When evaluating an airframe that has a wing taper ratio that is less than 1.0 (I used 0.5), it was found that the velocity needed to calculate the necessary lift was 13.215339717762241 m/s. While this is close to the velocity needed for the optimized airframe, it is still larger; therefore, it is not as optimal. This shows that as the wing taper ratio is decreased, the velocity needed to lift 0.5 kilograms increases, making it sub-optimal. You can also see that an airframe with a wing taper ratio of 1.0 has a lift coefficient distribution that is closer to the optimal elliptical distribution than the airframe with a wing taper ratio of 0.5 (see figures 8 and 9).

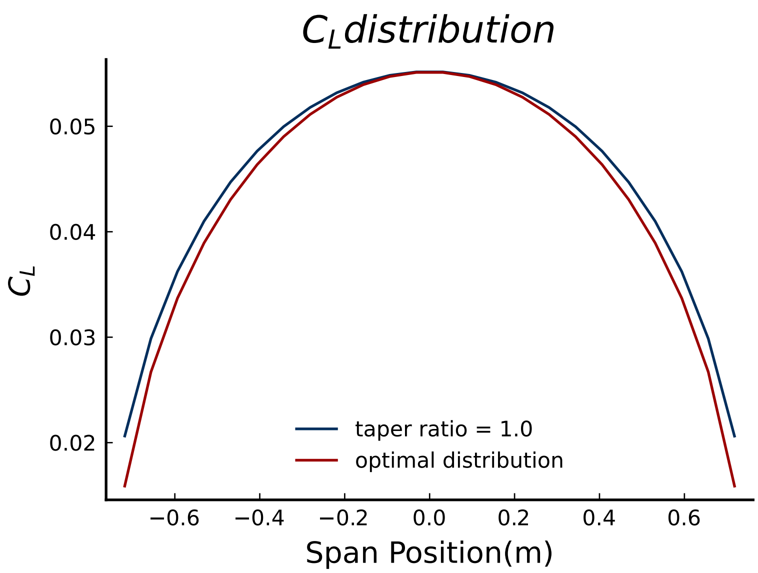

Fig. 8: *This figure shows the lift coefficient distribution for a taper ratio of 1.0 vs. the optimal elliptical distribution.*

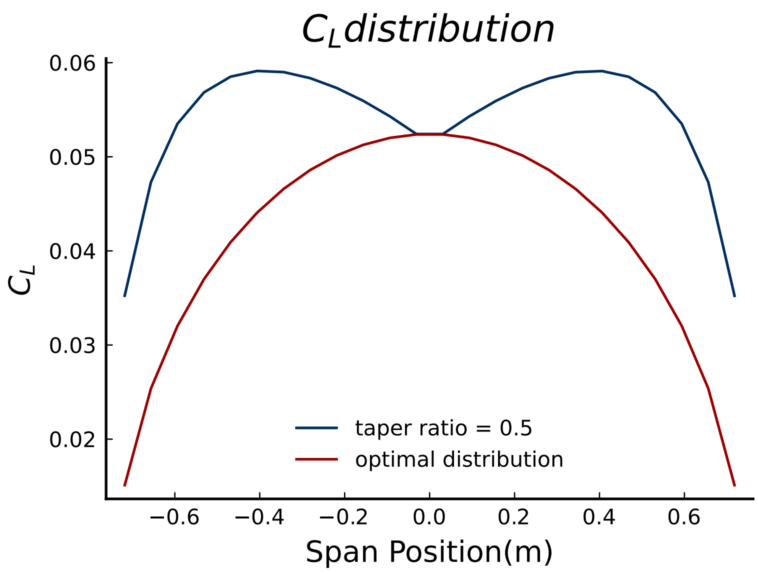

Fig. 9: *This figure shows the lift coefficient distribution for a taper ratio of 0.5 vs. the optimal elliptical distribution.*

Plots showing the lift coefficients and drag coefficients vs. angle of attack for these 2 designs are given (see figures 10 and 11).

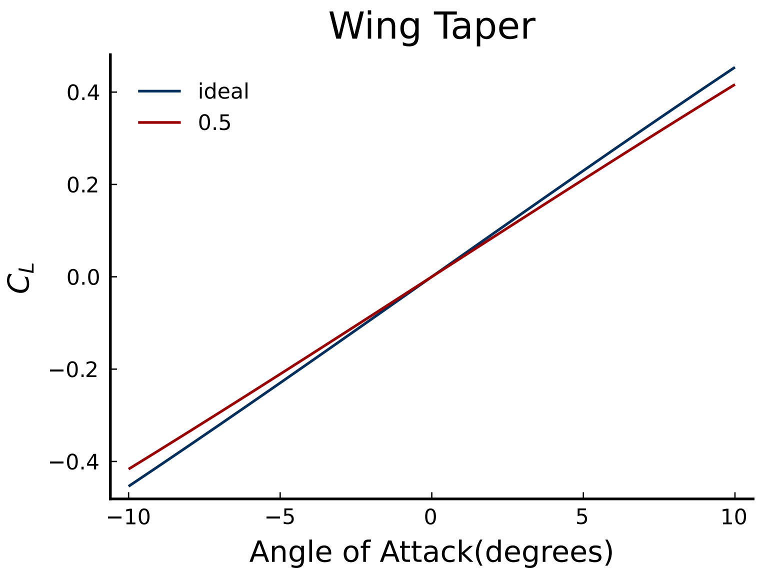

Fig. 10: *This figure shows the lift coefficients for varying angles of attack for the 2 designs evaluated using different wing tip tapers*

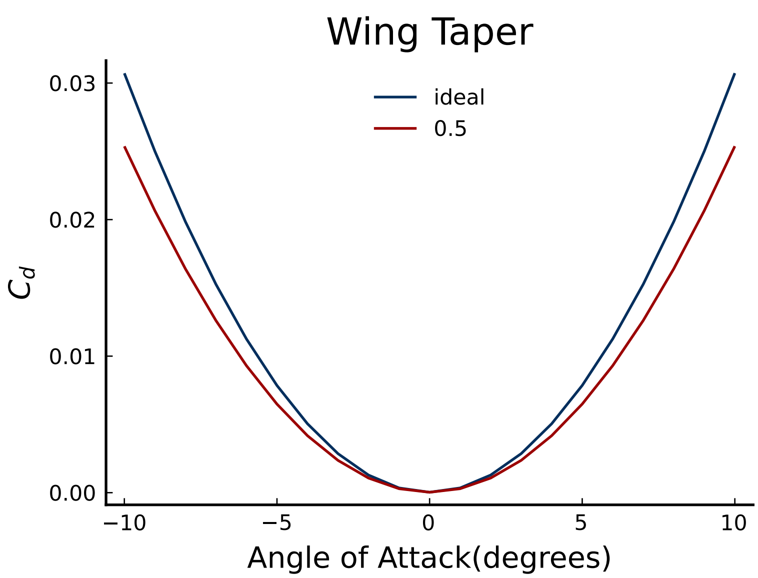

Fig. 11: *This figure shows the drag coefficients for varying angles of attack for the 2 designs evaluated using different wing tip tapers*

The design of an airframe with a wing taper ratio of 0.5 is shown in figure

12.

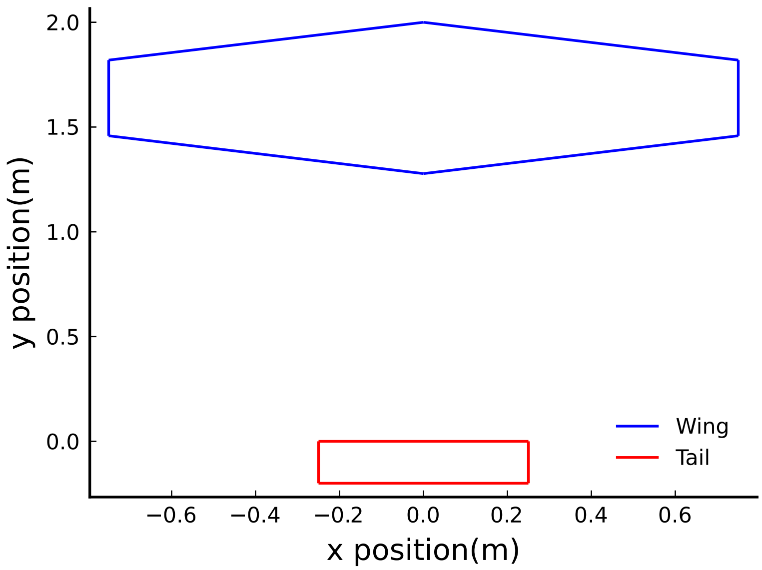

Fig. 12: *This figure shows the design of an airframe with a wing taper ratio of 0.5.*

4 Appendix

- Engineering Design - an iterative process that engineers follow to develop a product that accomplishes a given task (see figure 13).

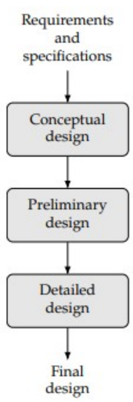

Fig. 13: *This figure shows the steps of the engineering design process.*

- Design Optimization Process - s a tool that can replace an iterative design process to accelerate the design cycle and obtain better results (see figure 14).

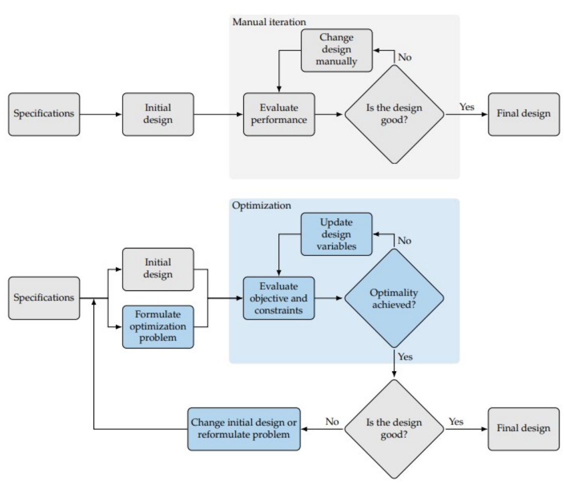

Fig. 14: *This figure shows the steps of the engineering design optimization process.*

- Objective Function - the design optimization process requires the designer to translate their intent to a mathematical statement that can then be solved by an optimization algorithm
- Design Variables - the variables that describe the system, must not depend on each other or any other parameter