Airframe Design Write Up

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1 Optimization

Optimization is not an uncommon idea. As humans, we want to get the best version of something that we possibly can; what is the purpose of using something if it can be better? Inevitably, the importance of optimization translates directly to engineering principles.

Optimization can be relatively simple or extremely complicated. Perhaps we are optimizing the area of a fenced off space that contains only two variables, or we are designing an aircraft with hundreds of variables. Regardless of the scale or complexity of the problem, the foundational principles of optimization remain constant. As Ning and Martins explain in their book "Engineering Design Optimization", optimization consists of a few parts: an objective function, design variables, and constraints. The design variables are the things that are being changed in order to get an optimal solution. The amount of design variables can vary from being a few to a few hundred or even more. The objective function is the value that we are trying to optimize; this can range from the lift coefficient on an aircraft to the mileage on a car. The objective function is made up of the design variables and uses them to compute the value that we are trying to optimize. Finally, the constraints are used to put restrictions on what our variables can be. This can range from a simple domain of values that a variable can rest inside or a structural coefficient that must be met in order for the solution to be legitimate.

On a quick note, optimization processes come in a lot of different forms. They can range from gradient based solvers to methods that evaluate a lot of different possible solutions at the same time and brute force their way to a solution. The method that is used for optimization is dependent on the situation at hand, and it takes a bit of intuition to find the best method for a specific problem.

2 Goals for Assignment Three

For assignment three, design an aircraft that:

- Increases my objective value that I determine
- Can lift 0.5 kilograms and doesn't exceed a wing span of 1.5 meters

- Is statically and dynamically stable

3 Which Optimizer to Use

Julia has a decent selection of optimizer programs to run for a problem like this. I originally was using Optim.jl, and overall, it was good to use. The set up for it was easy, and it could get good solutions out. However, I ran into problems using Optim.jl regarding constraints and optimization efficiency. Due to this, I switched to SNOW.jl, which was put together by Professor Ning. This package ran very well, and met the requirements that I needed for this assignment.

4 Design Variables

I originally was planning on having around 18 design variables that consisted of changing lengths on the wing, horizontal stabilizer, and vertical stabilizer; changing dihedral for each of the components; changing sweep for each of these components; adjusting horizontal and vertical stabilizer positioning; changing chord lengths for each of these components; and adjusting twist. However, I quickly discovered that this was an expensive optimization and probably out of my skill level. In order to make the process manageable, I dropped the number of variables down to nine, and these variables only changed the sweep, span, dihedral, and positioning of the wing, horizontal stabilizer, and vertical stabilizer. I set reasonable values for the chord lengths and twist instead of making them variables. When I made this switch, I started getting faster and more consistent results that satisfied my goals for this assignment.

5 Conditions for My Optimization

Since the assignment wants a plane that is statically and dynamically stable and can lift a load of 0.5 kilograms, I went to work to find some values that I could make constraints in order to satisfy these needs.

Firstly, I know that a mass of 0.5 kilograms applies a force of 4.9 Newtons, so the lift generated by my plane must be able to create a force of at least 4.9 Newtons. To find this force, I used the equation:

$$L = \frac{1}{2}\rho V_\infty^2 A C_L$$

Using this equation would allow me to force my optimization to be able to lift the necessary mass.

I also wanted my plane to be dynamically and statically stable, so I began to look at what modes of flight are common in an aircraft. Some of these modes include phugoid motion; short-period oscillation; dutch roll; and a slow spiral. Each of these have corresponding stability derivatives that tell whether the aircraft can stabilize itself if it falls into one of these undesirable modes of flight or whether the plane will lose control and inevitably crash. I figured out whether these specific derivatives that correspond to these modes were supposed to be positive or negative from Professor Ning's book "Flight Vehicle Design".

To combat a Phugoid and Short-Period Oscillation flight mode, we want the $C_{m\alpha}$ stability derivative to be negative. This means that as the plane begins to pitch up or down, the aircraft will naturally create a pitching moment that will bring the plane back to a stable state.

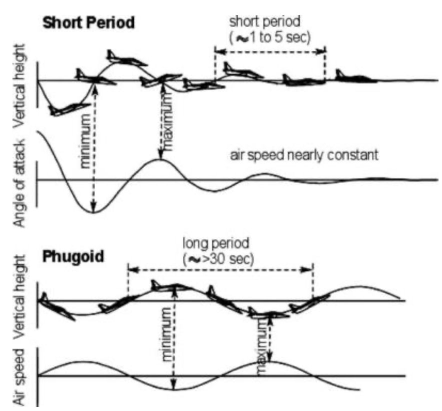

Figure 1: Illustration of Phugoid and Short-Period Oscillation modes (courtesy of Studfiles.net)

For the dutch roll, we want the C_{lb} stability derivative to be negative because as the plane begins to roll, we want a negative moment in order to bring the plane back to a resting state.

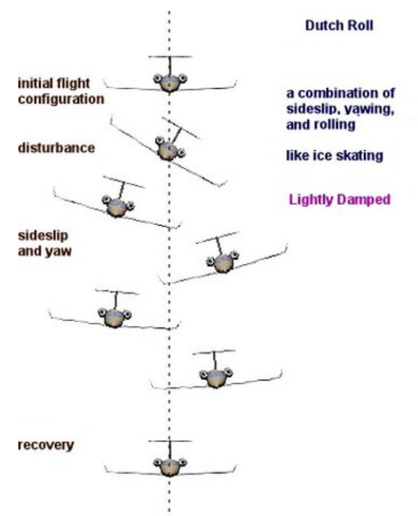

Figure 2: Illustration of the Dutch Roll mode (courtesy of Leeham News and Analysis)

And for the slow spiral, C_{nb} must be positive since a positive yawing moment is desirable when a plane begins to spiral out of control. The reason that this derivative is positive and not negative like the others is because under standard sign convention, a positive yaw moment correlates to a negative beta angle. This is different from the fact that for $C_{m\alpha}$, a positive pitching moment corresponds to a positive α value.

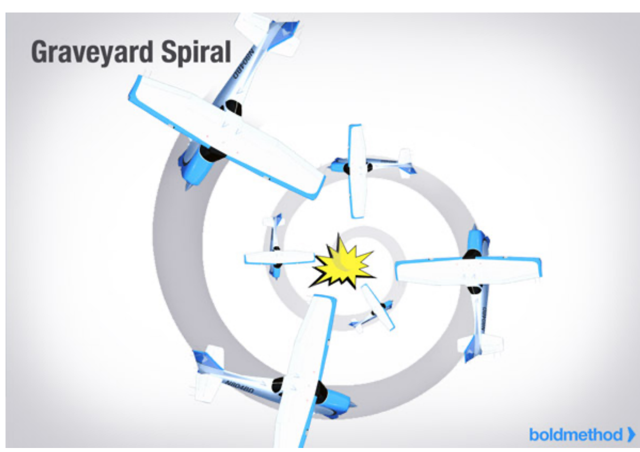

Figure 3: Illustration of the Slow Spiral mode (courtesy of Boldmethod)

6 Objective Value

Picking a good objective value is one of the most important parts of an optimization problem, and it is also one of the more tricky parts. It's easy to choose an objective value that should be a constraint and vice-versa. After considering what I would want out of my aircraft, I chose to make the lift-to-drag ratio my objective value. A good plane should have a high lift to drag ratio, so this seemed like a fitting value to optimize.

7 Final Results

All of these values are in units of meters, and each constraint was satisfied through the optimizer.

Additionally, I assumed that my plane was flying at $22\frac{m}{s}$ and at an angle of attack of 2^o.

7.1 Wing

xle = 0.5
yle = 0.75
zle = 0.2
chord = [0.3, 0.2]
theta = [0.0, 0.0]
phi = [0.0, 0.0]

7.2 Horizontal Stabilizer

xle = 0.4
yle = 0.3
zle = 0.0
chord = [0.2, 0.2]
theta = [0.0, 0.0]
phi = [0.0, 0.0]

7.3 Vertical Stabilizer

xle = 0.3
yle = 0.0
zle = 0.3
chord = [0.2, 0.1]
theta = [0.0, 0.0]
phi = [0.0, 0.0]

7.4 Horizontal and Vertical Stabilizer Positioning

t = 1.6

7.5 Max Lift-to-Drag Ratio

$\frac{C_L}{C_D} = 121.846$

7.6 Constraints

Lift Force = 17.714 Newtons

Cma = -0.0122

Cnb = 0.262

Clb = -0.0206

8 Takeaways

A major thing that I learned from this assignment is that it is best to take optimization one slow step at a time. I was very quick to jump into an advanced problem, and when problems arose, I didn't know where to start fixing them from. It was only when I broke the problem down into smaller pieces that I was able to get the results that I needed.