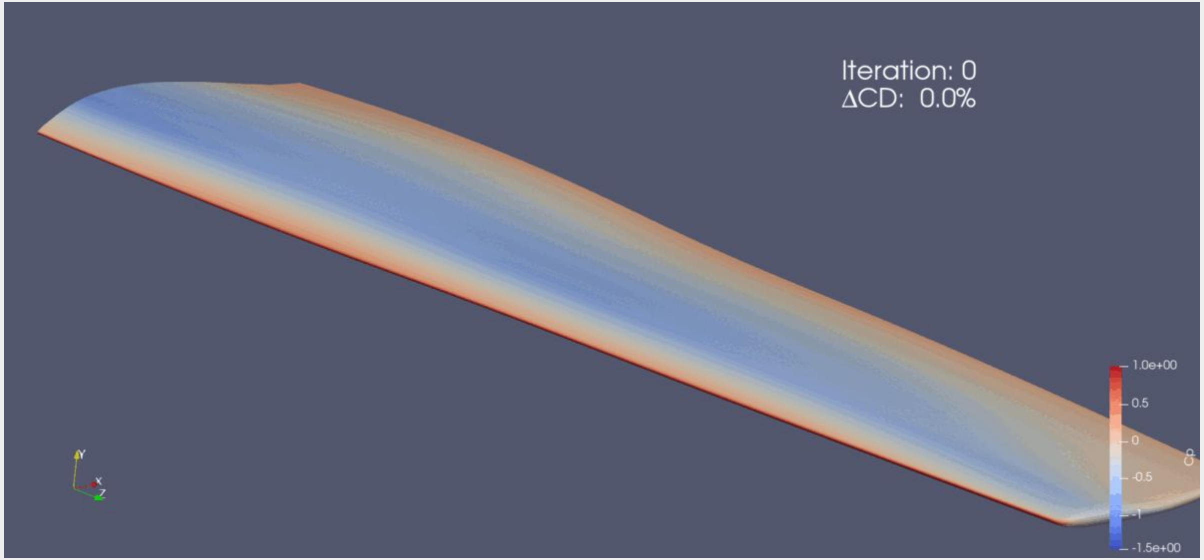
Quantifying the effect of adding planform variables to a UAV wing aerodynamic optimization



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7/28/22

Introduction

- The aerospace engineering industry typically uses manual design considerations to optimize wing performance.
- Computational optimization methods can potentially be more accurate than using conventional experience.
- Eventual dependence on computational optimization will make the design testing process more physically accessible and less costly.
- UAVs are futuristic technologies used for aerial imagery, inspections, and mapping.

NASA Dresden’s F-15A Remotely Piloted Research Vehicle (RPRV)

Wing Geometry

$$Taper\ Ratio\ \lambda = \frac{tip\ chord}{root\ chord} = \frac{C_t}{C_r}$$

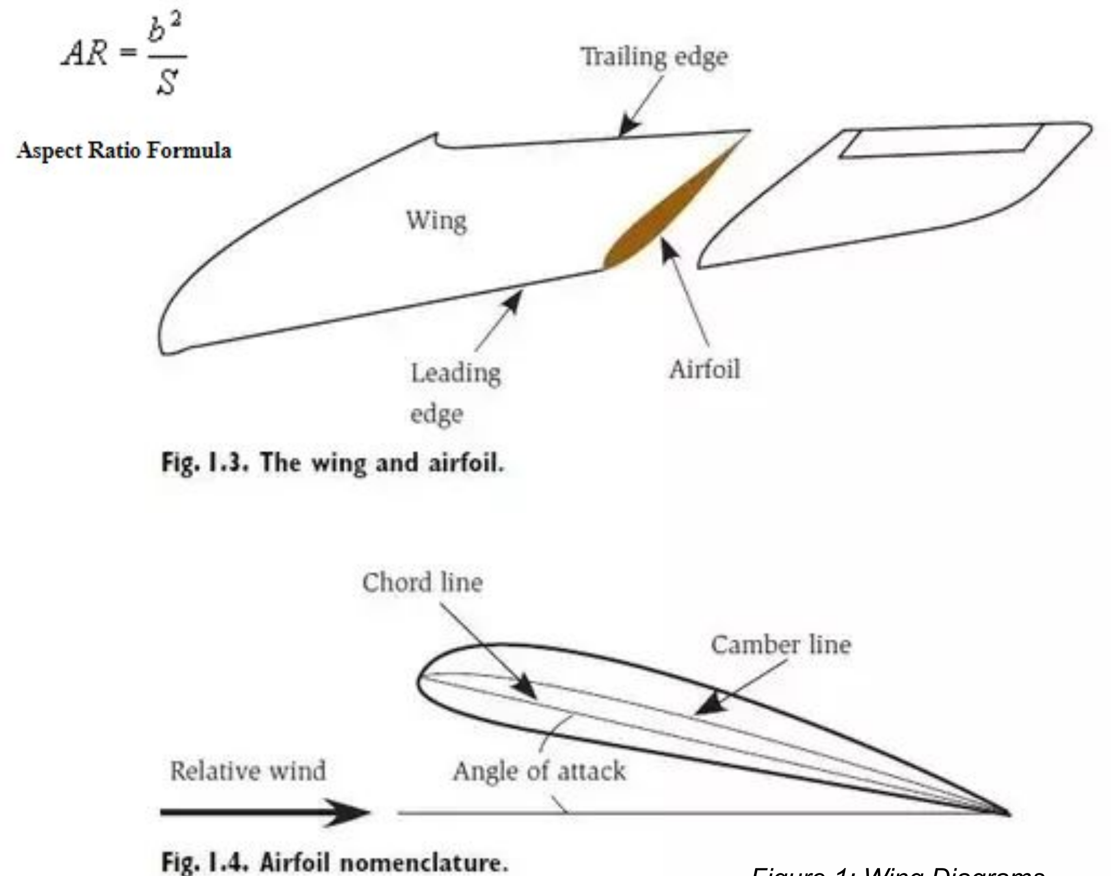
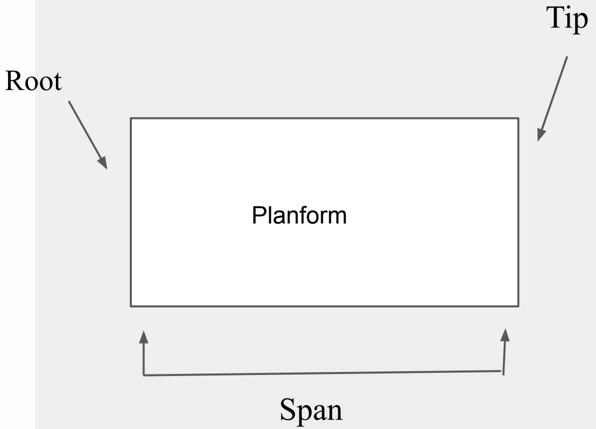


Figure 1: Wing Diagrams



Research Objective

Research question: Will the addition of planform variables to a shape-only case increase or decrease the drag of an optimized airfoil?

This study allows for the determination of variables that result in the largest drag reduction. The potential impact on the aerospace industry is great as it allows for concentrated attention on key variables, reducing wasted resources.

Objective function: Drag coefficient

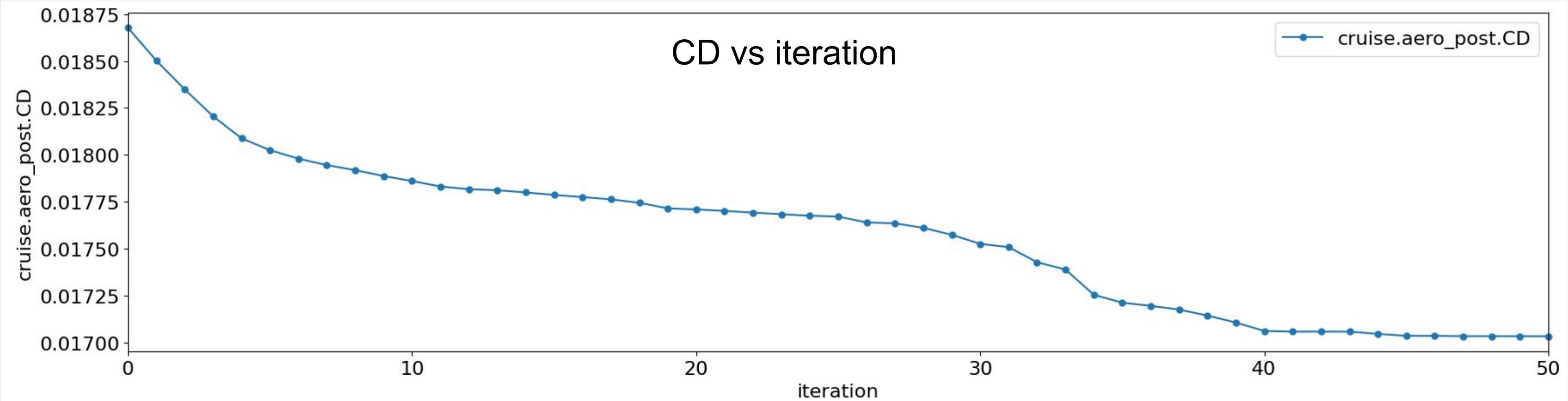


Figure 2: CD vs Iteration Plot

Software Framework

The DAFoam (Discrete Adjoint with OpenFOAM for High-fidelity Multidisciplinary Design Optimization) software can automatically optimize an existing design according to given parameters and output a percentage of the design's performance increase.

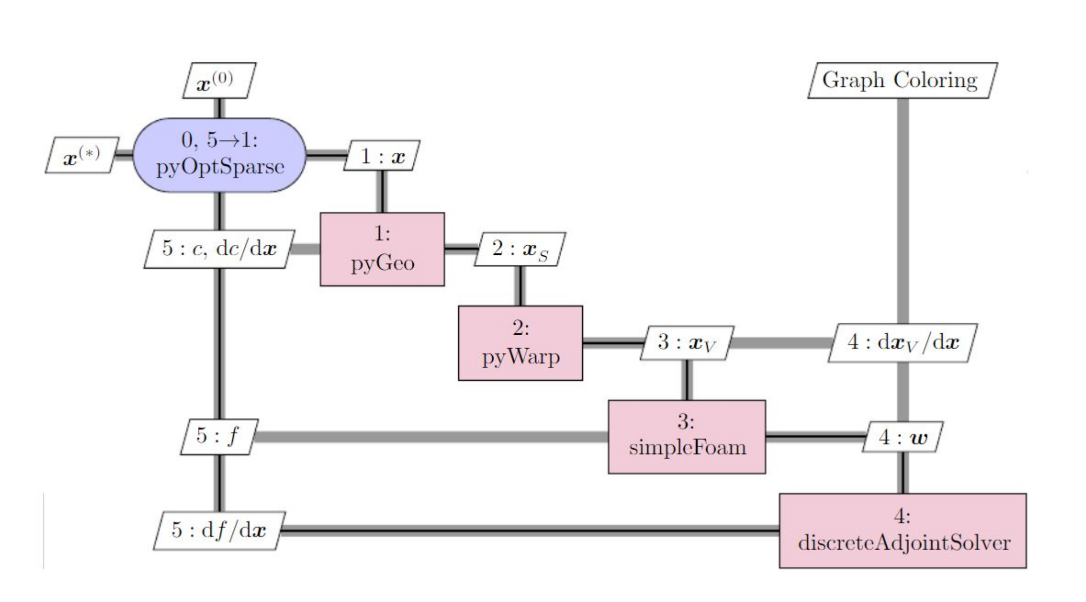


Figure 3: DAFoam Design Matrix

pyOptSparse	variable input (SNOPT)
pyGeo	surface geometry (FFD)
pyWarp	mesh deformation
simpleFoam	CFD solver (OPENFoam)
discreteAdjointSolver	DAFoam

Table 1: DAFoam Modules

Computation Process

- An HPC (high performance computer) was used to lessen computational time.
- Used Stampede2, a Linux-based UTexas Austin supercomputer.
- ICX-normal computing nodes for shorter queue times.
- Cases were each run on 4 nodes (computers), 80 cores/node. 320 tasks (commands)/case.

Figure 4: Stampede2

```
#!/bin/bash
#SBATCH -A TG-ATM140019       # project ID
#SBATCH -J planform_12                # job name
#SBATCH -o log-%j.txt              # output and error file name (%j expands to jobID)
#SBATCH -n 320                # total number of mpi tasks requested
#SBATCH -N 4                # total number of nodes
#SBATCH -p icx-normal              # queue (partition) -- normal, development, etc.
#SBATCH -t 10:00:00           # run time (hh:mm:ss)
#SBATCH --mail-type=ALL       # setup email alert
#SBATCH --mail-user=ppak@bu.edu
```

Figure 5: HPC submission .sh script

Python Interface

- runscript.py is a python script defining parameters, variables, tolerances, and constraints for a given case.
- Tolerances and parameters were kept constant for all cases.

Parameter	Variable	Value	Unit
Freestream Velocity	U0	100.0	m/s
Freestream Pressure	p0	101325.0	kPa
Temperature	T0	300.0	K
Target Lift Coefficient	CL_target	0.375	
Angle of attack	aoa0	2.0	deg
Planform area	A0	3.0	m^2
Mach Number	M	0.3	
Reynolds Number	Re	2.20E+05	
Span	span0	3.0	m
Chord	chord0	1.0	m

Table 2: runscript.py parameters

Case Breakdown

Case	VarTpes	Constraints	Total Variables	Total Constraints
Shape	aoa, twist, shape	thickcon, volcon, lecon, telcon, CL	126	764
Planform 1	aoa, taper, span	volcon, CL	4	3
Planform 2	aoa, taper	CL	3	2
Planform 3	aoa, span	CL	2	2
Combination	Aoa, twist, shape, taper, span	thickcon, volcon, lecon, telcon, CL	129	764

Table 3: Case Descriptions

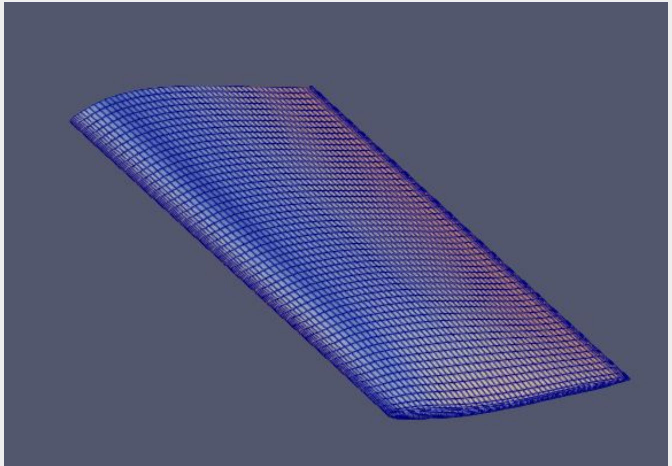


Figure 6: Shape Case Wing Mesh

Shape Case Results

Drag reduction	8.79%
Runtime	16:08:46
Aspect Ratio	3
Taper ratio	1

Table 4: Shape Case Results

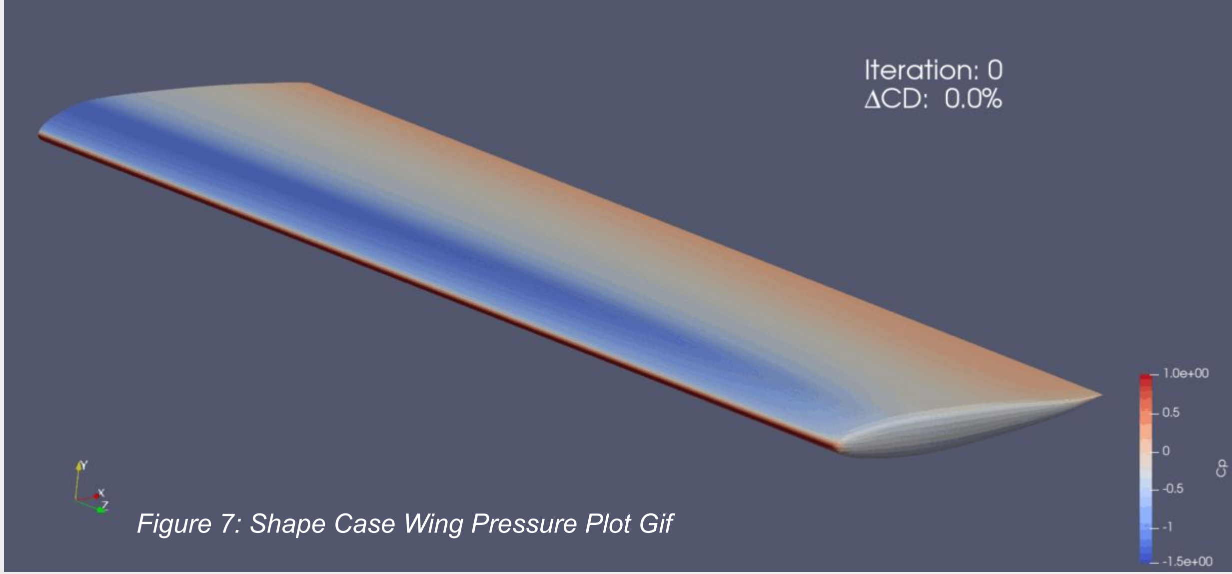


Figure 7: Shape Case Wing Pressure Plot Gif

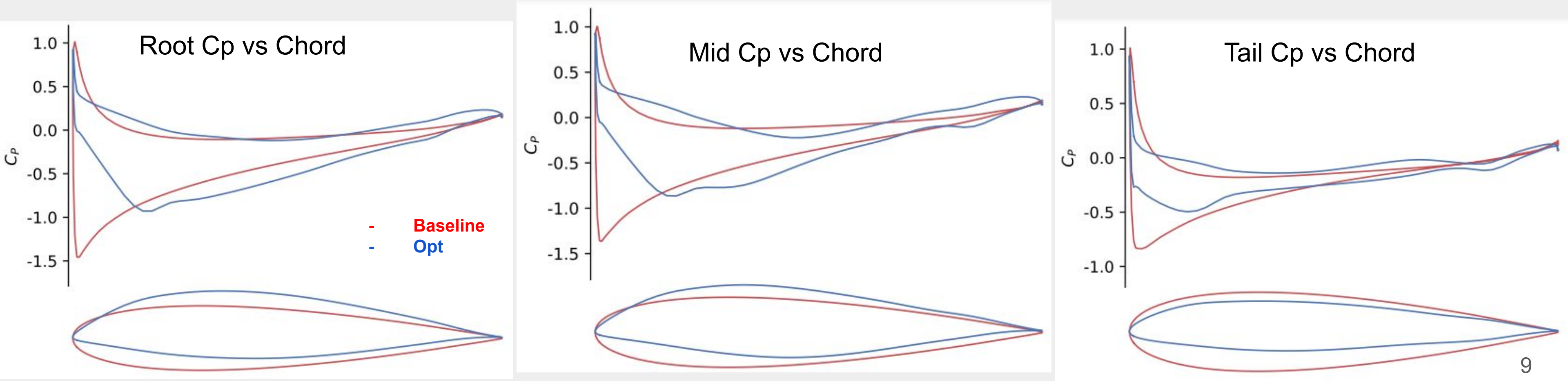


Figure 8: Shape Case Plots

Planform Case 1 Results

Drag reduction	11.50%
Runtime	2:41:44
Aspect Ratio	5.57
Taper ratio	1

Table 5: Planform Case 1 Results

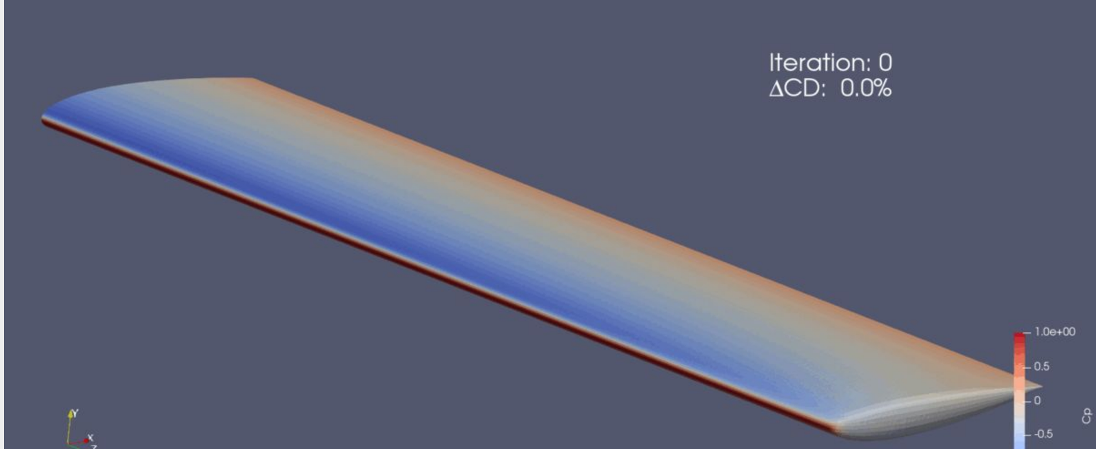


Figure 9: Planform 1 Case Wing Pressure Plot Gif

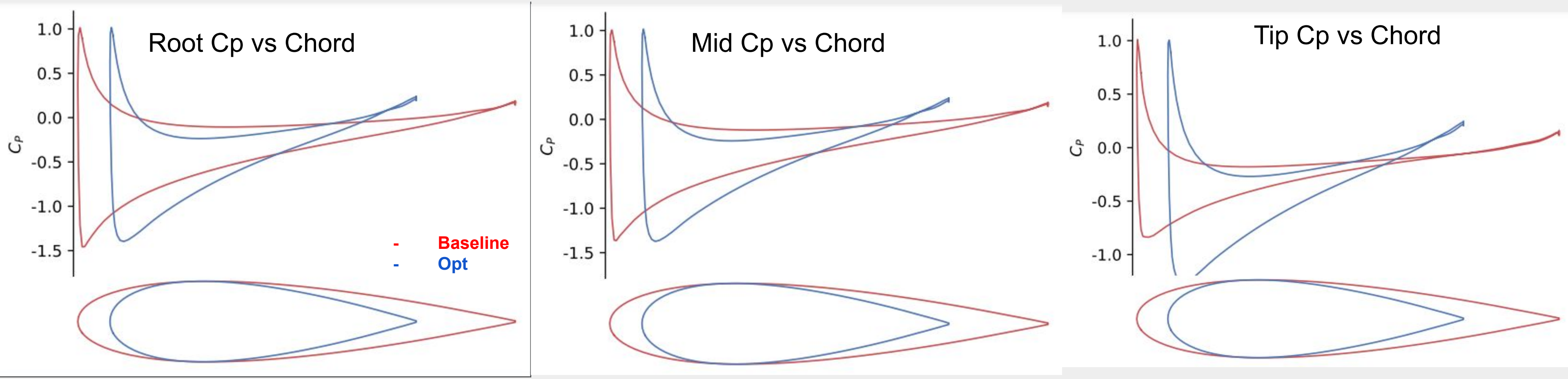


Figure 10: Planform Case 1 Plots

Planform Case 2 Results

Drag reduction	8.47%
Runtime	4:43:05
Aspect Ratio	2
Taper ratio	0.5

Table 6: Planform Case 2 Results

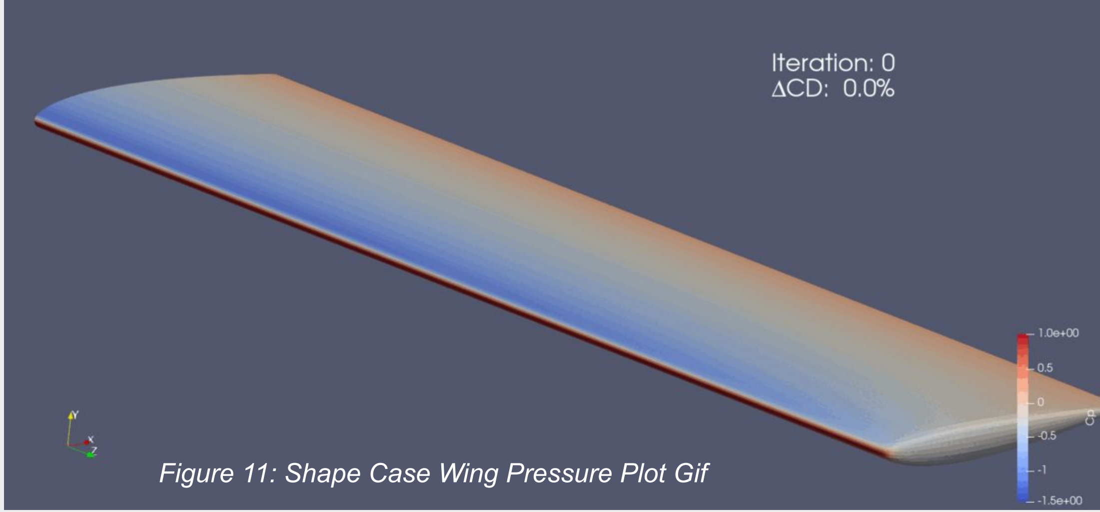


Figure 11: Shape Case Wing Pressure Plot Gif

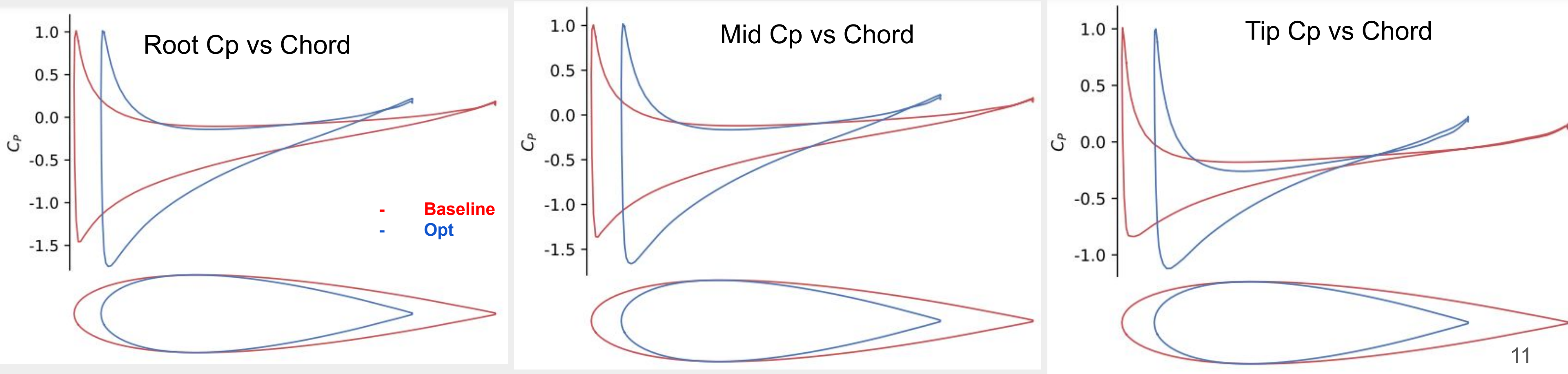


Figure 12: Planform Case 1 Plots

Planform Case 3 Results

Drag reduction	3.49%
Runtime	3:35:14
Aspect Ratio	3.59
Taper ratio	1

Table 7: Planform Case 3 Results

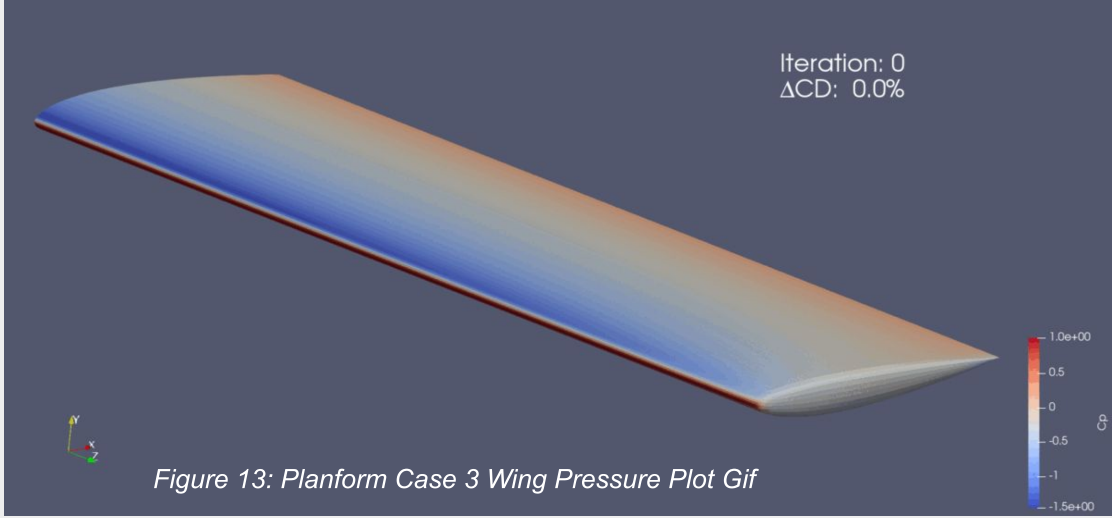


Figure 13: Planform Case 3 Wing Pressure Plot Gif

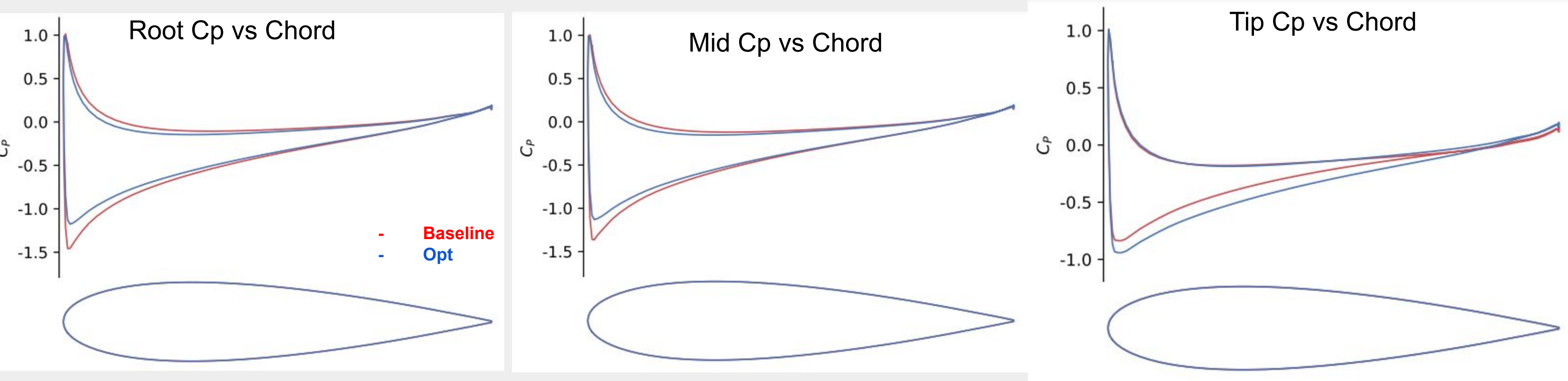


Figure 14: Planform Case 3 Graphs

Combined Case Results

Drag reduction	17.02%
Runtime	12:16:12
Aspect Ratio	3.68
Taper ratio	0.89

Table 8: Combined Case Results

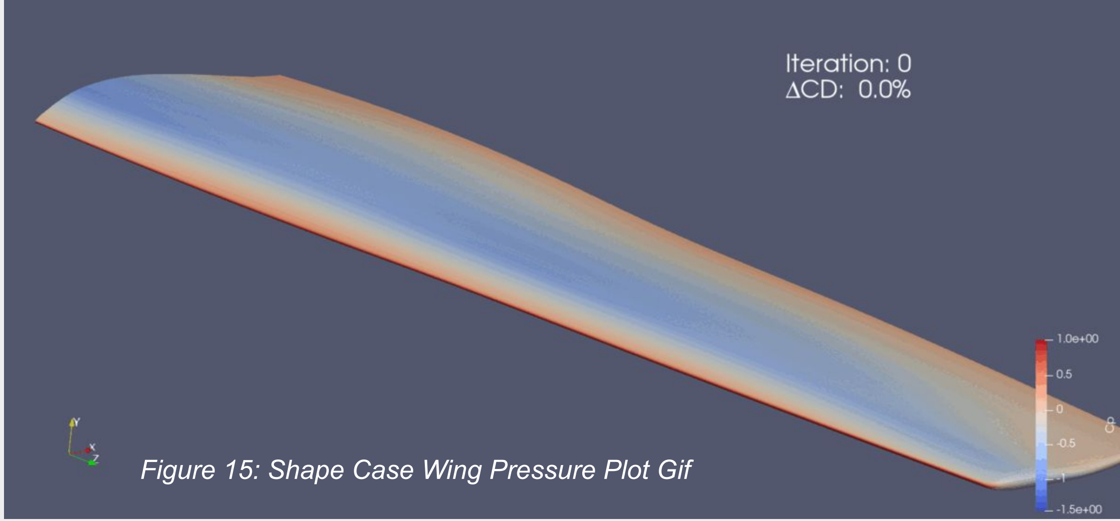


Figure 15: Shape Case Wing Pressure Plot Gif

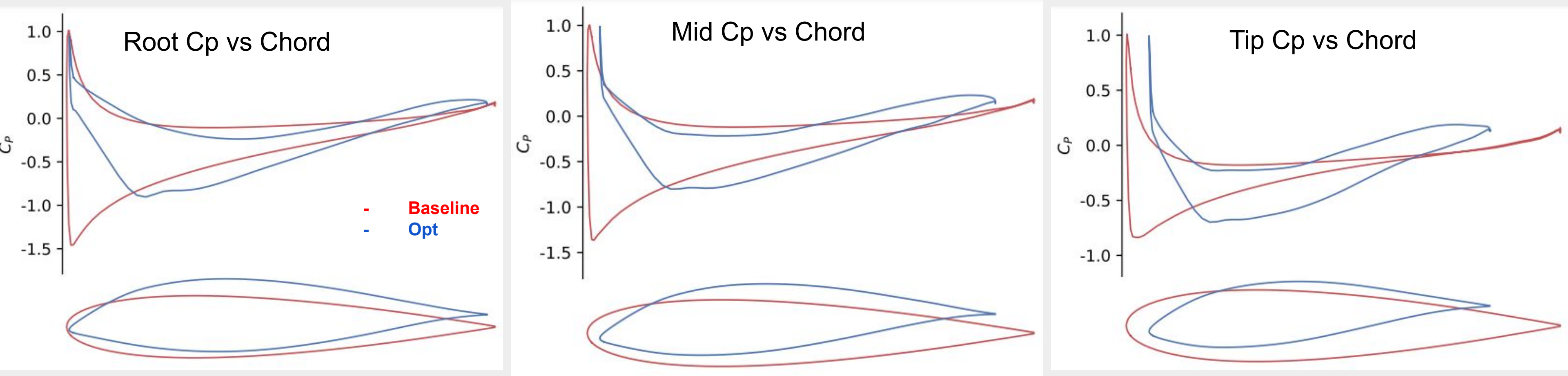


Figure 16: Combined Case Graphs

Conclusions

- The addition of planform variables to a shape case will further decrease the drag by 8.23%.
- As drag decreases, taper ratio decreases and aspect ratio increases.
- The most time-efficient case was the planform 1 case.

- **Verification:** Wind tunnel testing.
- The consistency of the results can be determined using other airfoil shapes and running cases with various flight conditions.

- **Future studies:** Account for stalling using ailerons.
- Consider weight to account for induced drag from a longer span.

Acknowledgements

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